MICROMORPHOLOGICAL ANALYSIS OF THE SEDIMENTS AND SOILS FROM THE GAULT SITE, A CLOVIS SITE IN CENTRAL TEXAS

A Thesis

by

HEIDI MARIE LUCHSINGER

Submitted to the Office of Graduate Studies of
Texas A&M University
in partial fulfillment of the requirements for the degree of

MASTER OF ARTS

December 2002

Major Subject: Anthropology

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Approved as to style and content by:

Michael R. Waters (Chair of Committee)	Lee C. Nordt (Member)
Harry J. Shafer (Member)	Paul Goldberg (Member)
Larry P. Wilding (Member)	David L. Carlson (Head of Department)

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ABSTRACT

Micromorphological Analysis of the Sediments and Soils from the Gault Site,
a Clovis Site in Central Texas. (December 2002)
Heidi Marie Luchsinger, B.A., Barnard College
Chair of Advisory Committee: Dr. Michael R. Waters

The Gault site is a Paleoindian site (ca. 11,500-8500 BP) in Central Texas that contains an unusual abundance of cultural material for this period. Due to the importance of this site for Paleoindian archaeology, a broad-scale geoarchaeological investigation was undertaken in order to construct a stratigraphic and temporal framework and reconstruct site formation processes and paleoenvironmental history. Micromorphological analysis was incorporated into this geoarchaeological study to clarify several issues that were not readily understood during excavation. This micromorphological study had four research objectives: 1) evaluation of the origin of calcium carbonate nodules found throughout the site to give indication of the extent of pedogenesis; 2) assessment of the impact of groundwater on each stratigraphic unit; 3) evaluation of additional post-depositional processes including bioturbation to determine integrity of the site; and 4) search for evidence of occupation surfaces on the microscale that were not visible during excavation. Results based on micromorphological and soil characterization analyses indicate that calcium carbonate nodules at this site are mostly pedogenic although some carbonates were inherited from alluvial or colluvial sources. In addition, groundwater had a significant impact on sediments and the preservation of organic materials due to an aquitard present in Unit 3a that perched the water table into overlying sediments causing groundwater to flow laterally during periods of high discharge and seep upwards during periods of low discharge. Bioturbation by small organisms such as earthworms and ants was evident in all stratigraphic units. It is likely that bioturbation caused the destruction of discrete occupation surfaces, clear stratigraphic breaks, and prehistoric organic remains. Finally, this analysis was able to offer insights for reconstructing the paleoenvironment of the Gault site, and may suggest the presence of a Clovis-Age drought.

For David

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Over the course of this project, I have been very fortunate to work with a committee made up of some of the most talented and insightful members of their respective fields. Dr. Michael Waters, committee chair, has offered me many learning opportunities over the past three years and has always provided sound advice and encouragement. Dr. Harry Shafer continually provoked my interest in the archaeology of the Paleoindian and Archaic periods through archaeological seminars and fieldwork. It has been an honor to have worked with Dr. Larry Wilding who has been a source of inspiration not only for his intellect but also for his sense of humor and perspective. I am grateful to Dr. Wilding for having his Soil Microfabric Analysis class (Spring 2000) collect and process the first set of samples from the Gault site that gave this project its initial jump-start. Thanks also to Dr. Lee Nordt (Baylor University) for his long-distance support and thought-provoking questions that significantly improved this project. Finally, thanks to Dr. Paul Goldberg (Boston University) who initially inspired me to pursue this field through his geoarchaeology class in the Spring of 1998. His encouragement pulled me through some of the more daunting phases of this project.

In addition to my committee, there are a number of other people that I would like to thank. Thanks to Dr. Michael Collins for his support, encouragement, and help in the field. Dr. Richard Drees has played a significant role in this project and I thank him for all of his patience. He generously spent much time advising me in the lab and I am a much wiser scientist because of this experience. Dr. Charles Hallmark could not have provided a better or more challenging introduction to soil science my first year at Texas A&M and provided me the tools that were fundamental for this project. I also thank Dr. Hallmark who assisted in the description of soil horizons during the sampling trip in January of 2000 and for allowing me to process my samples at the Soil Characterization Lab. I thank Donna Prochaska (Soil Characterization Lab) who spent many hours patiently training me. In the Geology department, I thank Dr. Christopher Mathewson and Lloyd Morris for granting access to their largest rock saw so that I could cut my samples in the Fall of 2000. Thanks to all of the students of my Microfabric Analysis class who collected and analyzed the set of samples taken in January of 2000: Phillip Owens, Paul Rindfleisch, Ryan Mersmann, Yuji Niino, Brad Driessen, and Domingo Rivas.

I thank the Department of Anthropology for their support, particularly Dr. David Carlson, Karen Taylor, Angie Shafer, and Don Delucia. Dr. Wayne Smith generously gave his time when I was in great need of help for illustrations and the poster that I presented at the annual meeting at the *Society for American Archaeology* held in Denver in March 2001. In addition, fellow students and colleagues Dawn Alexander, Charlotte Donald, Jason Barrett, and Mary Barnes have helped me in the field and during research and I thank you for lending me a hand throughout this project.

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CHAPTER I

INTRODUCTION

The Gault Site

The Gault site is located in Central Texas, at the headwaters of Buttermilk Creek near the eastern edge of the Edwards Plateau. The archaeological components at this open-air site are contained within alluvial and colluvial deposits that overlie limestone bedrock containing abundant outcrops of Edwards chert. From 1929-30, the first archaeological excavation at the Gault site was undertaken by J. E. Pearce of the University of Texas. Over the next sixty years, the site was disturbed by artifact collectors until 1991, when the Texas Archeological Research Laboratory (TARL) at the University of Texas at Austin excavated several test units. Since 1991, further excavation has been conducted under the direction of Michael Collins (TARL) and by co-principal investigators Michael Waters and Harry Shafer (Texas A&M University), and Jon Lohse (TARL).

As a result of these recent excavations, the Gault site has drawn much interest among archaeologists because of its unusual wealth of Paleoindian cultural material that dates to ca. 11,500-8500 BP. At present, over 200,000 artifacts have been collected from the Gault site, and excavations have revealed Clovis, Folsom, Plainview, Scottsbluff, Angostura, Archaic, and Late Prehistoric lithic artifacts (Collins and Hester 1998; Hester 1998). Based on this evidence, human occupation at the Gault site was

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This thesis follows the style and format of *American Antiquity*.

nearly continuous for 11,000 years. The unusual site preservation, abundance of Paleoindian artifacts, and sequential occupation lasting from the Clovis period until the Late Prehistoric period will substantially enhance our understanding of the earliest origins of humans in North America.

Geoarchaeological and Micromorphological Investigations at the Gault Site

Open-air sites are characteristic of the Paleoindian period in North America, although they are frequently disturbed or destroyed. Because these sites usually have a complex stratigraphy, geoarchaeological studies are critical to interpreting the archaeological record. These studies aim to reconstruct the depositional and post-depositional history of a site, the paleolandscape and local paleoenvironment, and evaluate the degree of site disturbance.

From the earliest stages of project planning at the Gault site, geoarchaeology formed an integral part of the research design and fieldwork strategy. Geoarchaeological studies conducted by Michael Waters (Texas A&M University) provided the insight for collecting a comprehensive sample of artifacts. In addition, it was possible to construct the history of depositional processes that occurred at the site and the changes in the paleoenvironment that occurred over the past 15,000 years. This strategy places the site into a stratigraphic and temporal framework that defines reference points for all other components (e.g., archaeological features, artifacts, faunal and botanical remains).

The use of micromorphology as part of the geoarchaeological study at the Gault site was selected to supplement traditional geoarchaeological techniques (e.g., mapping and description of stratigraphy, particle-size analysis, chemical analysis, and collection of radiocarbon samples). The advantage of using micromorphological analysis in addition to these techniques is that it can decipher the microstratigraphy and reveal discrete traces of human behavior that would otherwise be destroyed through lab analyses of bulk samples (i.e., particle-size analysis) or not identified macroscopically from field observation (i.e., stratigraphic recording). In addition, particle size analysis does not differentiate between mineral and nonmineral particles, and many techniques are not capable of distinguishing the pedological, geological, or archaeological evidence that can all be imprinted on a single geologic unit (Goldberg 1992, 1998). Furthermore, some archaeological and microstratigraphic features are not evident in the field and are only later discovered in thin section (Macphail and Goldberg 1995). Such discrete archaeological features found in thin section can be potentially important to large-scale archaeological interpretations at sites such as the Gault site.

Some geoarchaeologists believe that although micromorphology is a useful and complementary approach to traditional methods, thin sections may not readily provide quantitative data (e.g., particle-size distribution, sorting, and skewness) compared to bulk sample analyses (Farrand 2001). This is not necessarily true, because techniques such as point-counting can generate quantitative data from thin sections. Quantitative data can be useful, particularly in the classification of sediments and soils as it is commonly used in soil science and sedimentology. However, an equally valid and readily available qualitative assessment of a particular feature found in thin section can be as significant as quantitative data derived from the same sample.

Past Uses of Micromorphology

Micromorphological analysis of sediments is one technique that has yet to be extensively applied in North American geoarchaeology. Micromorphology involves the analysis of intact, undisturbed, and vertically or horizontally oriented sediment samples in thin section (30 microns thick) under various powers of magnification (20-200x) (Courty et al. 1989). In thin section analysis, it is possible to locate geological, pedological, and archaeological features that can be important for understanding the geoarchaeology of a site that forms the basis for archaeological interpretations.

Through the use of micromorphology, it is possible to focus on paleoenvironmental reconstruction, in addition to reconstruction of three main components of the site matrix: sedimentary, pedological, and anthropogenic features. Thin section analysis can reveal origin of sediments, soil development, and other post-depositional processes, and the presence of cultural material (Courty 1992).

One of the advantages of using micromorphology in archaeology is that it can permanently document and preserve sediment. Photography and drawing cannot fully document the sediments and soils of a site, but this matrix can be preserved in impregnated blocks and thin sections (Macphail and Goldberg 1995). Specific characteristics that are pertinent to archaeological investigations and can be documented through micromorphology are summarized in Table 1.

It is important to emphasize that micromorphology should not be conducted in isolation. Other analytical studies supplement and reinforce conclusions based on

Table 1. Characteristics that can be observed in thin section (modified from Courty et al. 1989).

Category	Characteristic Type	Evidence in Thin Section
Sediments	Detrital	Inorganic or organic particles transported by wind, water, or gravity e.g., loess, alluvium, colluvium
	Biological	Diatoms, gastropod and pelecypod fragments
	Chemical, Biochemical	Spelothems, travertine, evaporites, limestone
	Organic	Peat, botanical remains
	Pyroclastic	Volcanic materials, blocks, bombs, lapilli, tuffs
Anthropogenic Features	Human Occupation	Ash, charcoal, artifacts, microdebitage, bone, living floors, coprolites, middens, botanical remains
	Construction Features	Mud brick, plaster, activity surfaces
	Land Use Practices	Land clearance, grazing, plowing, manuring, terracing, irrigation
Post-depositional Processes	Biological Activity	Animal and insect burrows and remains, plant burrows, fecal material, roots
	Seasonal Drying	Shrink-swell of clays
	Cryogenic Effects	Permafrost, freeze-thaw, gelifluction
	Chemical Weathering	Oxidation, reduction, hydration, dehydration, hydrolysis
	Movement of Water and Solutions	Translocation, depletion, and accumulation of soluble salts, calcium carbonate, iron, aluminum, manganese, silica

micromorphology (Goldberg 1992). In addition, collaboration with other specialized archaeological studies (e.g., paleoethnobotany, zooarchaeology) is beneficial for the micromorphologist, particularly in the reconstruction of the paleoenvironment (Macphail and Goldberg 1995). Lastly, analysis of thin sections can make geoarchaeological studies more efficient and economical by providing a resource for evaluating whether additional bulk sample analyses are necessary.

The use of micromorphology originated in soil science and dates back to the mid-20th century (Kubiena 1938, Wilding and Flach 1985). Its adoption by archaeologists however, has been slow and sporadic. In the 1950s, the first micromorphological samples from archaeological sites were collected and analyzed by pedologists Cornwall

(1953) and Dalrymple (1958). Nevertheless, the use of micromorphology at archaeological sites continued to be sporadic for another twenty years. Four obstacles delayed the use of micromorphology in archaeology: 1) difficulties with impregnating large sediment samples, 2) problems regarding the production of large thin sections, 3) lack of a standardized descriptive terminology, and 4) lack of a methodology for interpreting thin sections from archaeological sites (Courty et al., 1989).

The use of micromorphology began to emerge in archaeology as these obstacles were individually overcome. Advances in the impregnation of sediment samples with consolidation materials and thin section production techniques facilitated micromorphology and made it more accessible. In addition, advances in micromorphological techniques have played a role in its progress. By the mid-1960s, Brewer (1976) had advanced the systematic description of thin sections in *Fabric and Mineral Analysis of Soils*. Bullock et al. (1985) introduced descriptive terminology that was more practical for describing samples from archaeological sites in the *Handbook for Soil Thin Section Description*. Four years later, Courty, Goldberg, and Macphail published *Soils and Micromorphology in Archaeology* (1989), a handbook on this technique including methodology for interpreting samples from archaeological sites. They also illustrated this technique with specific case studies.

Although these advances facilitated the use of micromorphology at archaeological sites over the last two decades, this technique would not have been readily accepted without the dynamic changes that occurred in archaeology in the 1970s. During that time, the advancing front of processualism advocated the transformation of archaeology into a more scientific discipline (Renfrew 1976, Trigger 1989). In the following years, this undoubtedly promoted the growth of geoarchaeology and interest among archaeological circles in the potential for contributions from the earth sciences. As a result, archaeologists began to consider including geoarchaeological techniques such as micromorphology in their fieldwork.

In the early 1980s, Goldberg (1983) rejuvenated the idea of applying micromorphology to archaeological sites that had been casually considered in the 1950s by Cornwall and Dalrymple. Goldberg suggested that micromorphology could be applied to archaeological sites for inferring past human behavior and could aid in establishing how human behavior was spatially distributed across a site. Today, micromorphology is more commonly used in archaeology, although its acceptance has been slow, particularly in New World archaeology.

To date, micromorphology has been well documented at only a few sites in North America: Dust Cave, Alabama (Sherwood 2001); Meadowcroft Rockshelter, Pennsylvania (Goldberg and Arpin 1999); the Wilson-Leonard site, Texas (Goldberg 1998); and Keatley Creek, British Columbia (Goldberg 2000). At the Wilson-Leonard site, Goldberg (1998) used micromorphology to aid in understanding aspects of depositional and post-depositional processes attributed to natural or anthropogenic activities that could not be determined by bulk sample analysis or through field recording. Specifically, detailed information was discovered about the nature of calcium carbonates found throughout the site matrix in addition to human disturbance of particular cultural features (i.e., a human burial and burnt rock features). In addition, analysis of calcium carbonate morphology and its distribution throughout the site matrix showed that there was a variety of carbonate morphologies. Large nodules were predominant in the lowest unit and delicate hypocoatings were mostly found in overlying units. It was interpreted that these differences were related to changing soil moisture conditions over time caused by changes in climate. This reconstruction of the paleoclimate provided a significantly clearer understanding of human behavior at this site.

Research Objectives

Micromorphological samples were collected from the Gault site to aid in the broad-scale geoarchaeological investigations. These investigations were designed to address four main research questions that could not be answered through conventional methods. First, calcium carbonate nodules were found in all units throughout the site. These nodules either eroded from local parent materials and were deposited along with other sediments (lithogenic carbonates), or they were formed in place as a result of soil formation processes (pedogenic carbonates). The *in situ* formation of calcium carbonate nodules requires fairly extensive landscape stability and pedogenesis within a soil. Therefore, it was necessary to understand the origin of these carbonate nodules in order to evaluate the intensity of soil formation to delineate episodes of erosion, deposition, and pedogenesis and this influence on the archaeological record at the site.

Second, this study assessed the impact of groundwater on the preservation of artifacts and ecofacts buried in the site matrix. This is an important issue because the site is located next to a modern perennial stream and group of active springs. In addition, it was clear that modern water table levels affected stratigraphic units containing artifacts, because at times during excavation groundwater rose to partially submerge excavation units. In addition, organic materials were not well represented at the site. Therefore, alternating groundwater/oxidation environments was considered to be one of the reasons these materials were destroyed.

The third research objective was to evaluate other post-depositional processes that affected the site and determine the contextual integrity of the site. Bioturbation was evident from the burrowing casts of small organisms, such as worms and ants, commonly seen in the field. Therefore it was important to evaluate the contextual integrity of this site

The fourth objective was to look for evidence of occupation surfaces that were not readily visible in the field. Therefore, it was necessary to analyze these units under higher magnification through the use of micromorphology. This made it possible to search for evidence of charcoal, microdebitage, microscopic fabrics, and other archaeological evidence that might indicate that a surface was occupied in the past.

CHAPTER II

SITE SETTING

Modern Environment

Bedrock and Geomorphology

The Gault site is located at the headwaters of Buttermilk Creek, a first-order stream that cuts into the limestone bedrock of the Lampasas Cut Plain, a subregion of the Edwards Plateau. Approximately 10 km east of its source, Buttermilk Creek joins Salado Creek, which eventually drains into the Brazos River after joining the Lampasas and Little Rivers. The local bedrock is Edwards Limestone and Comanche Peak Limestone, part of the Lower Cretaceous Fredericksburg Group (Barnes 1974). The Texas A&M University excavation block is located on the southern margin of Buttermilk Creek, although archaeological material has been found over an area of 0.8 x 0.2 km (Figure 1). The site consists of a complex stratigraphy of multiple alluvial units and paleosols interspersed with colluvial deposits.

Bedrock underlying the Buttermilk Creek valley floor is composed of Edwards Limestone, consisting mainly of fine-grained limestone, dolomite, and chert (Barnes 1974). The limestone is aphanitic to fine grained, massive to thin bedded, hard, brittle with some rudistid biostromes and mostly miliolid biosparite. Dolomite is characteristically fine to very fine grained, porous, and medium gray to grayish brown. Edwards Limestone found in weathering zones is recrystallized, “honeycombed”, and

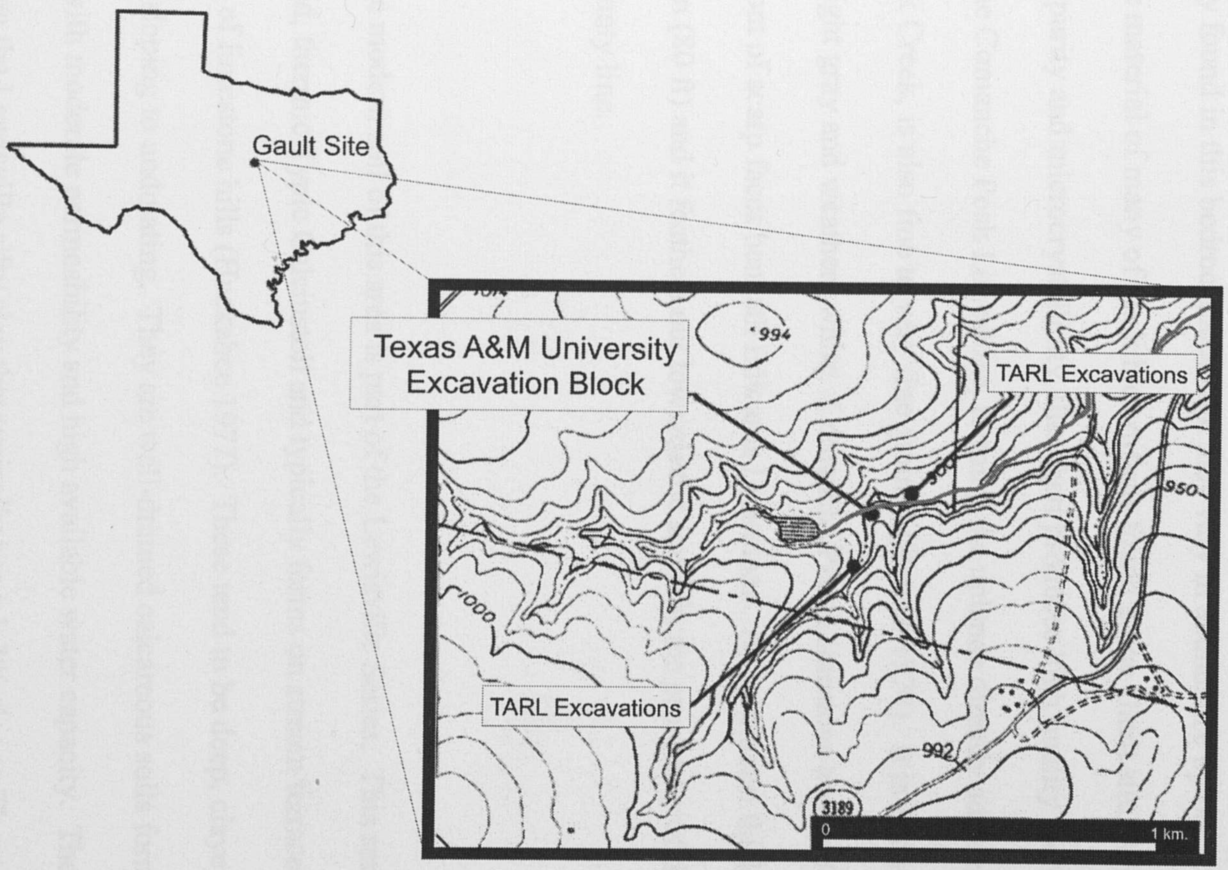


Figure 1. Location of the Texas A&M excavation block at the Gault site, Bell County, Texas.

cavernous. Across the landscape it forms flat areas and plateaus that are bordered by scarps. This bedrock ranges in thickness from about 18 to 107 m (60 to 350 ft) and grows thinner northward. Chert nodules and plates are white to light gray and are commonly found in this bedrock, although they vary in abundance by bed. This chert is the source material of many of the lithic artifacts found at the Gault site. With a high degree of purity and microcrystallinity, this chert produces high quality tools.

The Comanche Peak Limestone, forming the uplands directly adjacent to Buttermilk Creek, is also fine to very fine grained (Barnes 1974). It is fairly hard, nodular, light gray and weathers white. Comanche Peak Limestone can be found cropping out of scarp faces beneath Edwards Limestone. Its maximum thickness is about 25 m (80 ft) and it feathers out towards the south in the proximity of the Williams-Travis County line.

Soils

The modern soil of this area is part of the Lewisville Series. This series is a fine-silty, mixed, thermic Typic Calciustoll and typically forms on stream terraces and the footslopes of limestone hills (Huckabee 1977). These tend to be deep, clayey soils that are gently sloping to undulating. They are well-drained calcareous soils forming on alluvium with moderate permeability and high available water capacity. The Gault site is located on the Lewisville silty clay that typically has a 1-3% slope. These soils commonly have a surface horizon that is dark-brown silty clay and around 46 cm (18 in) thick. The next horizon is usually brown to strong-brown silty clay and can reach to 112 cm (44 in) in depth. The underlying horizon is a reddish-yellow silty clay that can be up to 178 cm (70 in) in depth. This soil is part of the ustic moisture soil regime and the thermic temperature regime common for Central Texas.

The Speck Series is a clayey, mixed, thermic Lithic Argiustoll. This is the soil of the surrounding uplands adjacent to the Gault site are noncalcareous clayey soils found gently sloping and undulating. They are shallow soils forming in noncalcareous, loamy and clayey material over limestone. They are well drained with slow permeability, low available water capacity, and medium runoff. The surface layer is typically a very dark grayish brown gravelly clay loam which is 20 cm (8 in) thick. The next horizon is a clay that typically reaches 48 cm (19 in) in depth. The upper portion of this horizon is reddish brown and the lower portion is dark reddish brown. Both horizons overlie indurated limestone bedrock.

Vegetation and Climate

The Gault site is located along a mesic valley floor with vegetation consisting of willow, elm, burr oak, walnut and bois d'arc trees. The adjacent xeric uplands consist of scrub oak, mesquite, and cacti. Average annual precipitation is around 82 cm (32 in) and annual temperature averages 18°C (65°F) with an average high of 24°C (76°F) and low of 12°C (54°F). Summer precipitation averages 20 cm (8 in) and in the winter, precipitation is around 15 cm (6 in). Spring precipitation is 23 cm (9 in) and autumn 25 cm (10 in) (Bomar 1995).

History of the Site

Stratigraphy

The stratigraphy of the Texas A&M excavation block (Figures 2 and 3) is divided into nine stratigraphic units (Figure 4). Unit 7b is missing from Figure 4 but is visible in portions of Figure 4 as the dark overlying surface sediment. Field descriptions were made by Michael Waters at a column in the central location of the excavation block, sampling location 1 (Figure 2), and represent eight of these nine stratigraphic units. Field descriptions were also made by Charles T. Hallmark and the Texas A&M Soil Micromorphology class of 2000 at another location within the Texas A&M University excavation block, sampling location 3 (Figure 2). Detailed field descriptions of each unit were taken at both sampling locations and are described in Appendix A.

The units present at sampling location 1 in the Texas A&M University excavation block were described by Michael Waters except unit 7b which was only present at sampling location 3 (Appendix A). These units make up the stratigraphy of this area from which all archaeological excavation was referenced. The field descriptions of Charles T. Hallmark (Texas A&M University) and the micromorphology class were focused on soil horizon and used terminology from the Soil Survey Division Staff (1993). However, unit 7b was not described at sampling location 1, so that description was incorporated from the description made by Hallmark.

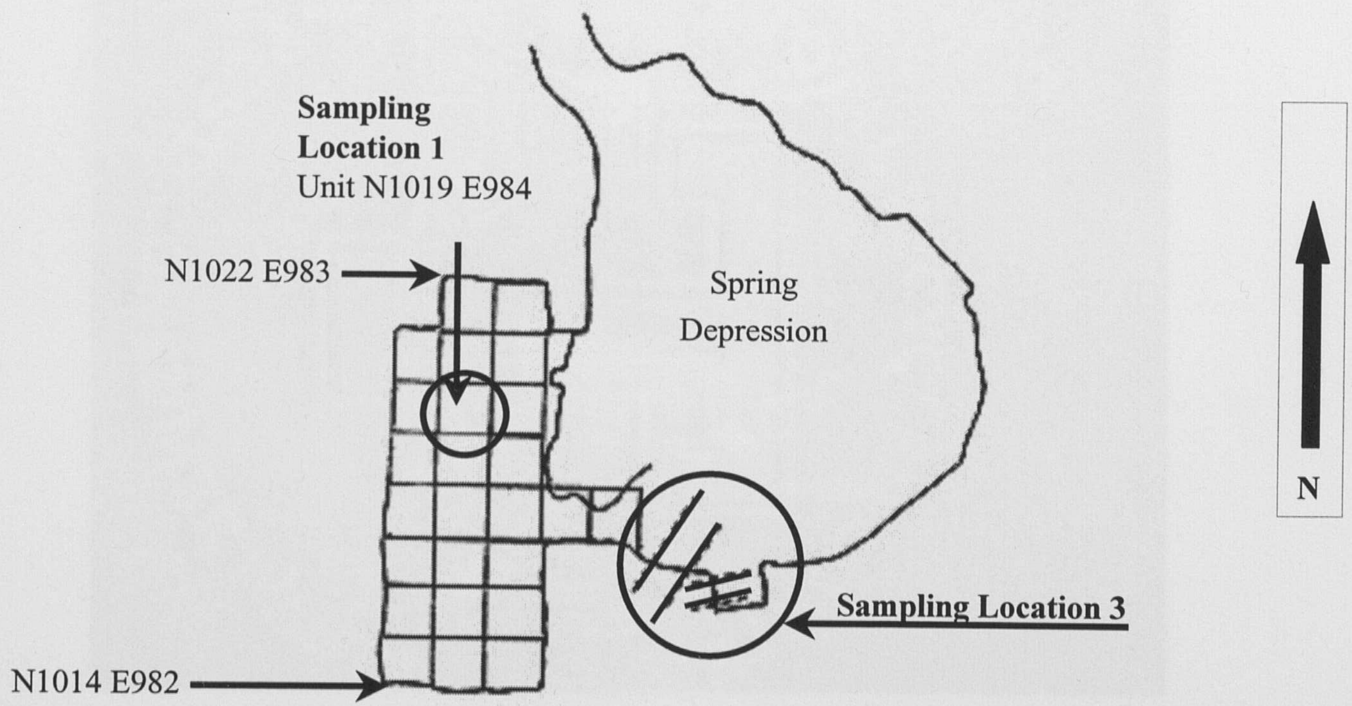


Figure 2. Texas A&M University excavation block at the Gault site.

Figure 3. Final excavation from the east with the west profile in the center (photo courtesy of Michael Waters).

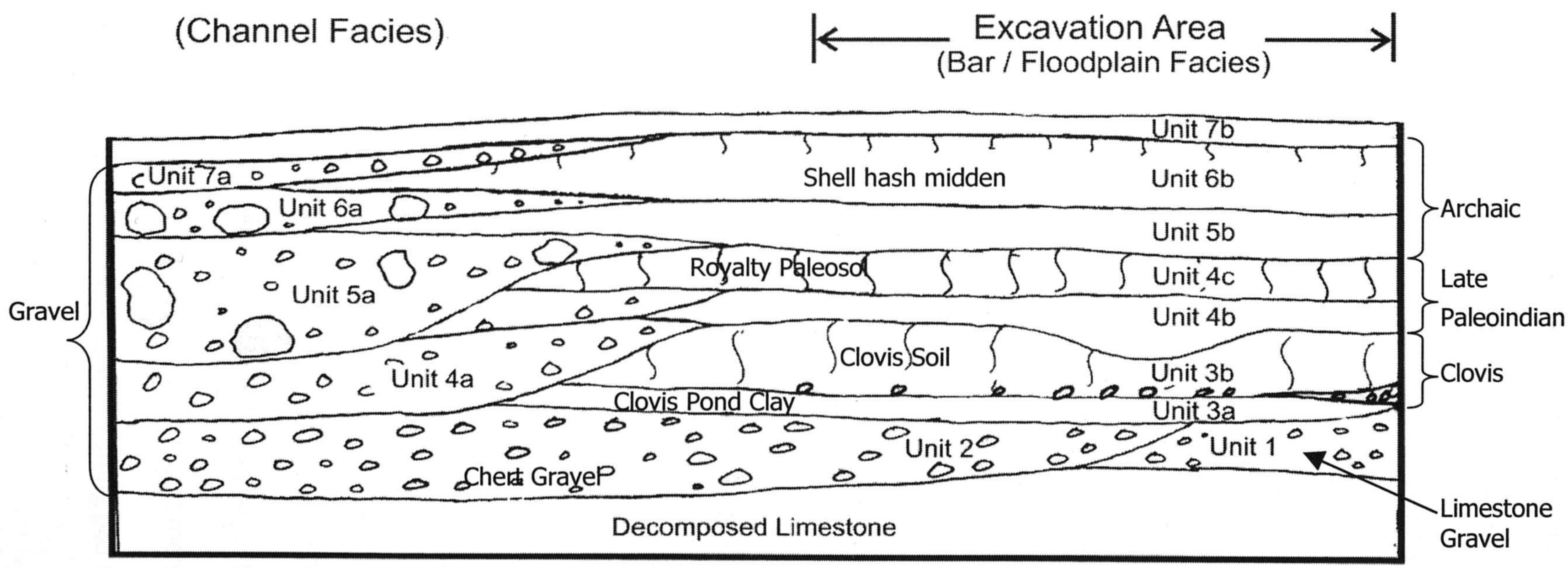


Figure 4. Generalized stratigraphy of the Gault site.

The first two units overlying the limestone bedrock are gravel units consisting of colluvial limestone (Unit 1) and alluvial chert (Unit 2) gravels. Unit 3a overlies these gravels and is a light brownish gray (dry: 10YR 6/2) to grayish brown (wet: 10YR 5/2) clay. This unit is approximately 20 cm thick and has vertic properties with clay wedges and strong irregular subangular blocky structure. Clay films are found in this unit in addition to slickensides on ped faces. Calcium carbonate nodules are found along ped faces and redox features found in this unit are similar to those found in overlying unit 3b, although they are more diffuse and do not occur along root channels. Unit 3a consists of pond clay sediments and in some portions of the site unit 3a is separated from unit 3b by a wedge of colluvial gravels and cobbles.

Unit 3b is a brown (dry: 10YR 5/3) to dark grayish brown (wet: 10YR 4/2) clay with subangular blocky structure and is 15-20 cm thick. Its upper boundary is abrupt and smooth. Calcium carbonate nodules are commonly found on ped faces. A coating of calcium carbonate was also found on artifacts and stones in this unit and the coating is always thicker on the bottom surface of artifacts. The concentration of calcium carbonate increases toward the bottom of this unit. Brown mottles were found along root channels that appear to extend from the overlying unit. Unit 3b is a floodplain and overbank deposit.

Unit 4b is a light brownish gray (dry: 10YR 6/2) to brown (wet: 10YR 5/3) clay with subangular blocky structure and a transitional boundary. This unit is 20-25 cm thick. Some subrounded cobbles (1-4 cm in diameter) and roots appear in this unit in addition to abundant soft calcium carbonate nodules along ped faces. Yellow redoximorphic mottles are similar to the mottles found in Unit 4c but are more prevalent, especially along root channels. Unit 4b consists of floodplain and overbank sediments.

Unit 4c is a grayish brown (dry: 10YR 5/2) to dark grayish brown (wet: 10YR 4/2) clay with subangular blocky structure and a transitional boundary that is ca. 25 cm thick. Unit 4c is a floodplain and overbank deposit. A few roots and subangular to subrounded rocks are found in this unit. Hard carbonate nodules (2-5 mm in diameter) along with smaller softer nodules are present on ped faces particularly in the lower half of the unit (Figure 5). In the upper sections, yellowish brown redoximorphic mottles (10YR 5/4) are found. Unit 4c appears to be a buried paleosol with an unconformable contact with its overlying and underlying units. It has well-developed subangular blocky structure and archaeological material has been found throughout this unit (Figure 5).

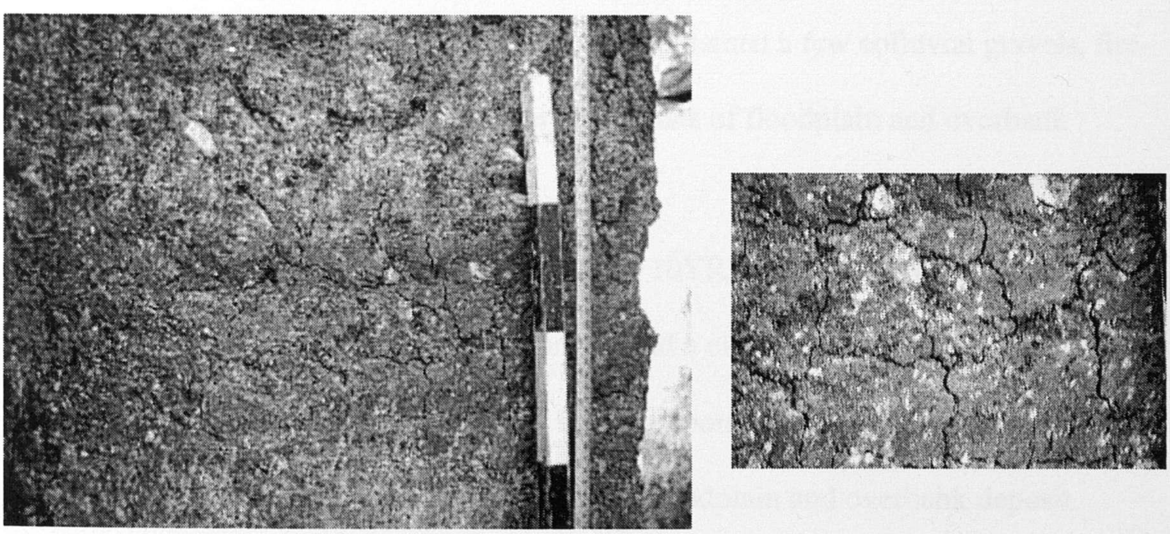


Figure 5. Subangular blocky structure and development of calcium carbonate nodules in Unit 4c.

This paleosol can be traced throughout the Gault site in most excavation units. It is possible that this paleosol correlates with the Royalty paleosol found at Fort Hood, but this is discussed in a later section.

Unit 5b is a light brownish gray (dry: 10YR 6/2) to brown (wet: 10YR 5/3) silty clay. This unit is 15 cm thick. It has a coarse granular structure and an abrupt boundary. Snail shells and bones were also found in this unit. Evidence of calcium carbonate accumulation is evident by the presence of calcium carbonate nodules (2-5 cm in diameter) and a thin coating of calcium carbonate on the bottom of artifacts and rocks (pendents). Yellow redoximorphic mottles (10YR 7/8) are common and found on calcium carbonate nodules. Unit 5b is a floodplain and overbank deposit.

Unit 6b is a grayish brown (dry: 10YR 5/2) to dark grayish brown (wet: 10YR 4/2) clay with coarse granular-crumb structure, and an abrupt boundary. This unit is around 10 cm thick. These sediments contain an Archaic midden and many intact and broken *Rabdotus* snail shells. This midden also contained a few colluvial gravels, fire-cracked rock, and Archaic artifacts. Unit 6b consists of floodplain and overbank sediments.

Unit 7b is a black to very dark gray (dry: 10YR 2/1-3/1) clay of the modern surface with a moderate fine granular structure and a clear smooth boundary. This unit is around 20-25 cm thick and contained a few fine roots, chert flakes, *Rabdotus* shells, and limestone pebbles and cobbles. Unit 7b is a floodplain and overbank deposit.

Sedimentation Rates

The relative age difference between the sediments above and below the paleosol is not the only factor in explaining the contrasting nature of the concentrations of redoximorphic features and calcium carbonates in these two groups of units as described above. It also appears that the nature of the local water regime dramatically changed sometime after 8500 BP. This is indicated by paleoclimatic data discussed later in Chapter V and in addition to the change in sedimentation rate following 8500 BP.

The mean sedimentation rate from the end of the Pleistocene (10,000 BP) until 8500 BP (units 1 through 4c) was 6.7 cm/100 years. The sediment depth for this time period (1500 years) at sampling location 1 was 100 cm. The units above the paleosol (units 5b, 6b, 7b) are also approximately 34 cm thick, but they formed over an 8500-year period, nearly six times the length of time it took to form the units below the paleosol. The mean sedimentation rate for the younger sediments changed to 0.4 cm/100 years, nearly a 94% decrease in sedimentation rate (Figures 6 and 7). This issue is later discussed with the interpretation of the micromorphology at the Gault site.

Archaeology of the Site

To date, lithic analysis of artifacts from the Gault site is ongoing. Moreover, faunal and stable carbon isotope analyses are still in progress and will be reported at a later date. There was an attempt to collect pollen and paleoethnobotanical remains, but this yielded no useful evidence. There have been repeated attempts to collect samples

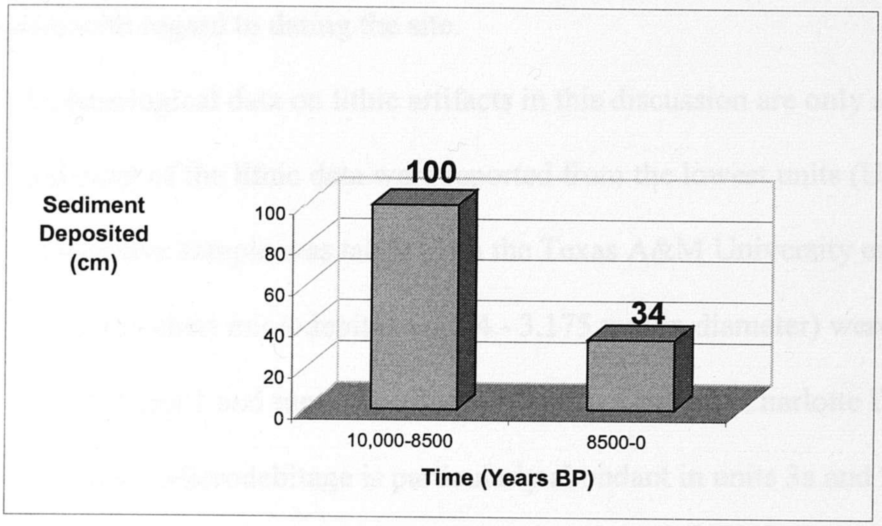


Figure 6. Thickness of sediment deposited over the past 10,000 years.

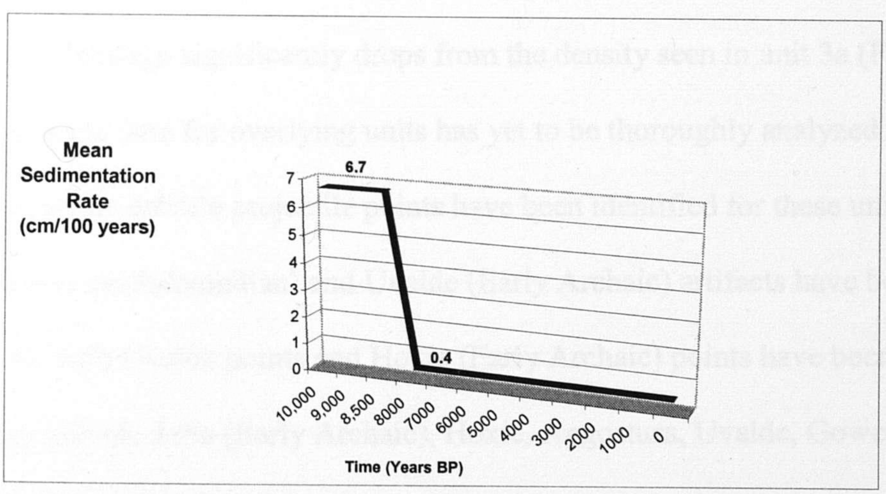


Figure 7. Mean sedimentation rate at the Gault site over the past 10,000 years.

for radiocarbon dating. A majority of the samples, however, have provided little data of importance with regard to dating the site.

Archaeological data on lithic artifacts in this discussion are only a representative sample and most of the lithic data were reported from the lowest units (Units 3 and 4). This representative sample was taken from the Texas A&M University excavation block. High densities of chert microdebitage (25.4 - 3.175 mm in diameter) were found in all units except for unit 1 and range into the thousands of pieces (Charlotte Donald, personal communication). Microdebitage is particularly abundant in units 3a and 3b, representing the Clovis period (Figure 8). Chert microdebitage was found in unit 2 in addition to a blade core and blades. In unit 3a, Clovis artifacts and chert microdebitage were found that were coated with calcium carbonate. Artifacts include blade cores, blades, and overshot flakes that have been identified to date. Unit 3b contains Clovis artifacts including large flakes, blades, blade cores, and overshot flakes. However, the density of chert microdebitage significantly drops from the density seen in unit 3a (Figure 8). Archaeological data for overlying units has yet to be thoroughly analyzed and quantified. However, a few datable projectile points have been identified for these units. In unit 4c Angostura (Late Paleoindian) and Uvalde (Early Archaic) artifacts have been excavated. In unit 5b, both Uvalde points and Hoxie (Early Archaic) points have been identified. In overlying unit 6b, Jetta (Early Archaic), Hoxie, Angostura, Uvalde, Gower (Early Archaic), and Nolan-like (Early Archaic) points have been found.

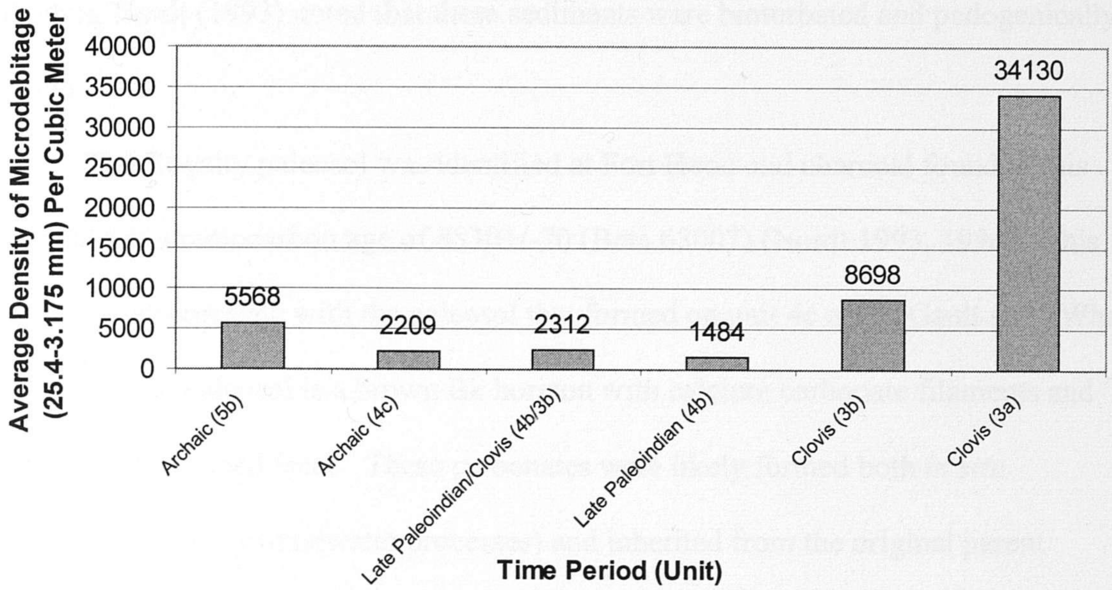


Figure 8. Average density of archaeological microdebitage from sampling in the Texas A&M University excavation block (data from Charlotte Donald n.d.).

Stratigraphic Correlations with Fort Hood

Units 3a, 3b, 4b, and 4c at the Gault site may correlate with an alluvial unit described by Nordt (1993) at Fort Hood, the Georgetown alluvium. According to the geomorphic and isotope data, some time between 15,000 and 10,000 years ago the climate became warmer and drier, accompanied by widespread channel trenching and abandonment of the Jackson alluvial terrace. Following, there was widespread valley alluviation that continued until 8500-8000 BP. The Georgetown alluvium consists of fine channel gravels and massive yellow-gray very fine sands and sandy clay loams. It is likely that these sediments were deposited by a uniform base flow because they are generally fine-grained and well-sorted. Evidence of reduction (gleying or gray coloring) in these sediments indicates that local water tables were also high during deposition. In addition, Nordt (1993) noted that these sediments were bioturbated and pedogenically altered.

The Royalty paleosol was identified at Fort Hood and charcoal found in this paleosol has a radiocarbon age of 8830+/-70 (Beta 63007) (Nordt 1993, 1996). This paleosol may correlate with the paleosol that formed on unit 4c at the Gault site. What remains of the paleosol is a brown Bk horizon with calcium carbonate filaments and threads found on ped faces. These carbonates were likely formed both *in situ* (pedogenically by groundwater processes) and inherited from the original parent material of the sediment (lithogenic). At Fort Hood, the Royalty paleosol was truncated ca. 7000 BP and cumulic sedimentation occurred over a 1000-year period.

The possible equivalent to unit 5b at the Gault site may be the Fort Hood alluvium that formed between 7000-4500 BP (Nordt 1993). Radiocarbon ages indicate that deposition occurred from ca. 6850-5200 BP. The Fort Hood alluvium consists of well-sorted fine to medium basal gravels underlying thick fine-grained channel fills. Deposition of this alluvium occurred during a period when the climate gradually became warmer and drier which slowed deposition allowing for soil development. At Fort Hood, this may have caused alluvial fan deposition and channel trenching. In addition, vegetation densities declined as a response to the drier climate and may have contributed to higher sediment yields for streams due to runoff. As a result, the parent material for the Fort Hood alluvium may have come from the Pleistocene soils that had been forming on upland terraces.

Unit 6b may correlate to the West Range alluvium at Fort Hood which was deposited between 4200 and 600 BP. This alluvium is more coarse than the underlying sediments and consists of coarse gravel and sand point bar deposits in addition to loamy overbank deposits. Nordt (1993) suggests that this shift to a coarser-grained sediment may be the consequence of a change to a wetter climate. The increase in moisture would allow the surrounding hillslopes to re-vegetate, while the increase in ground cover would protect sediments from eroding into their adjacent streams. An increase in moisture would also cause higher stream discharge and channel downcutting would occur. Downcutting would expose fresh bedrock as the source for the coarse-grained West Range alluvium. This process of alluviation may have been interrupted briefly from 3000-2000 BP when the climate shifted to a drier episode. This event is evident in the West Range alluvium by a small erosional conformity.

The correlative unit at Fort Hood for unit 7b at the Gault site may well be the Ford alluvium. This deposit expresses two weakly developed Ak horizons indicating that deposition was interrupted by periods of landscape stability. Microfossils were seen in thin section and most of the calcium carbonates must have been inherited from parent material because there is little evidence of pedogenically formed carbonates. These characteristics are also common in unit 7b.

CHAPTER III

METHODS

Field Sampling

Samples for micromorphological analysis were collected from three different locations within the Texas A&M University excavation block (Figure 9). Sampling location 1 is located in the southwestern corner of excavation unit N1019 E984 (Figure 10) and was sampled in April 2000. Samples at this location were taken from geological stratigraphic units that had been revealed by the archaeological excavation. Another set of samples was taken at sampling location 2 on the western face of the excavation block along E982 between units N1020 E982 and N1016 E 982 (Figures 11 and 12). These samples were also taken from select stratigraphic units the following January (2001) to supplement samples taken from sampling location 1. The third sampling location (Figures 13 and 14) was sampled in January of 2000 by graduate students of the micromorphology class from Texas A&M University under the direction of Dr. L.P. Wilding and Dr. L.R. Drees. Soil horizon descriptions were assisted by Dr. C.T. Hallmark. Sampling location 3 was located slightly upslope in the southeastern section of the Texas A&M University excavation block and samples were taken from designated soil horizons along the northern and eastern faces of excavation units N1017 E988.

Sample collection and impregnation methodology followed that described in Courty et al. 1989 and Drees 1999. Micromorphological samples were collected by

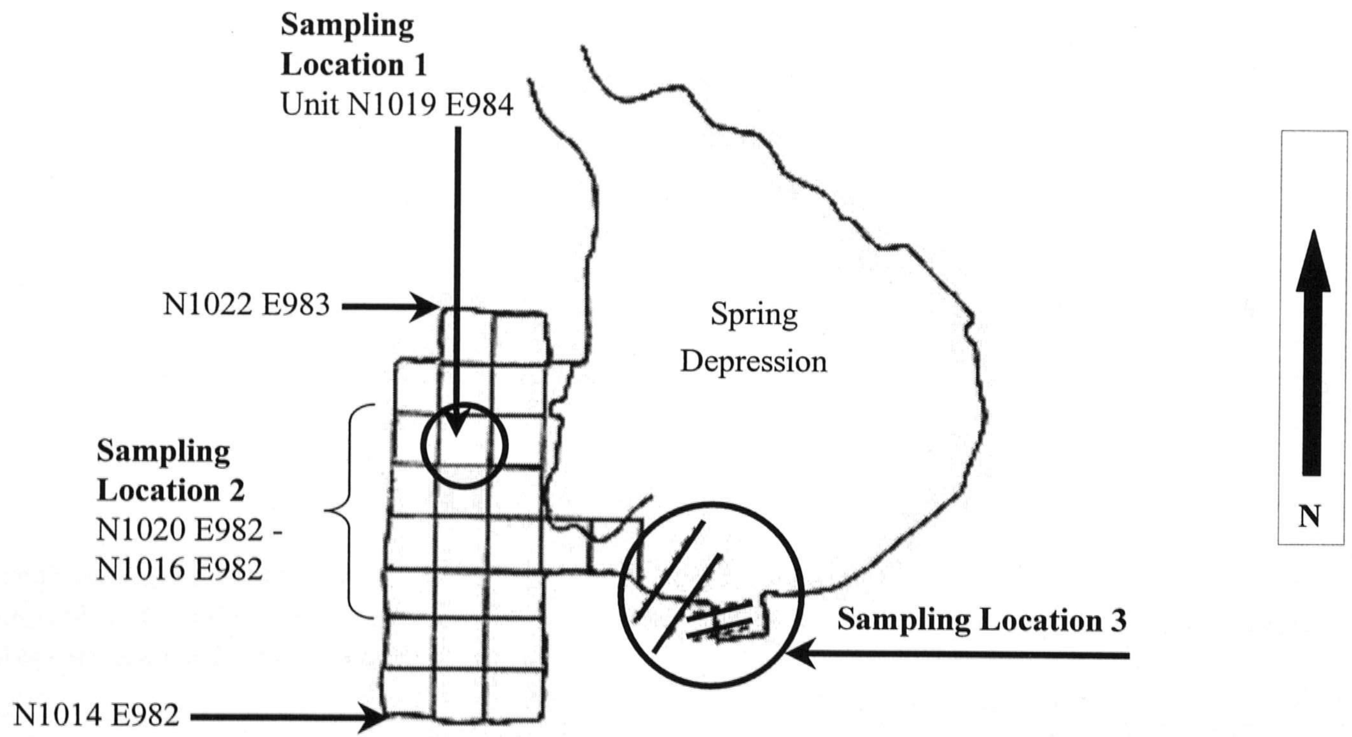


Figure 9. Texas A&M University excavation block and map of sampling locations for micromorphology at the Gault site.

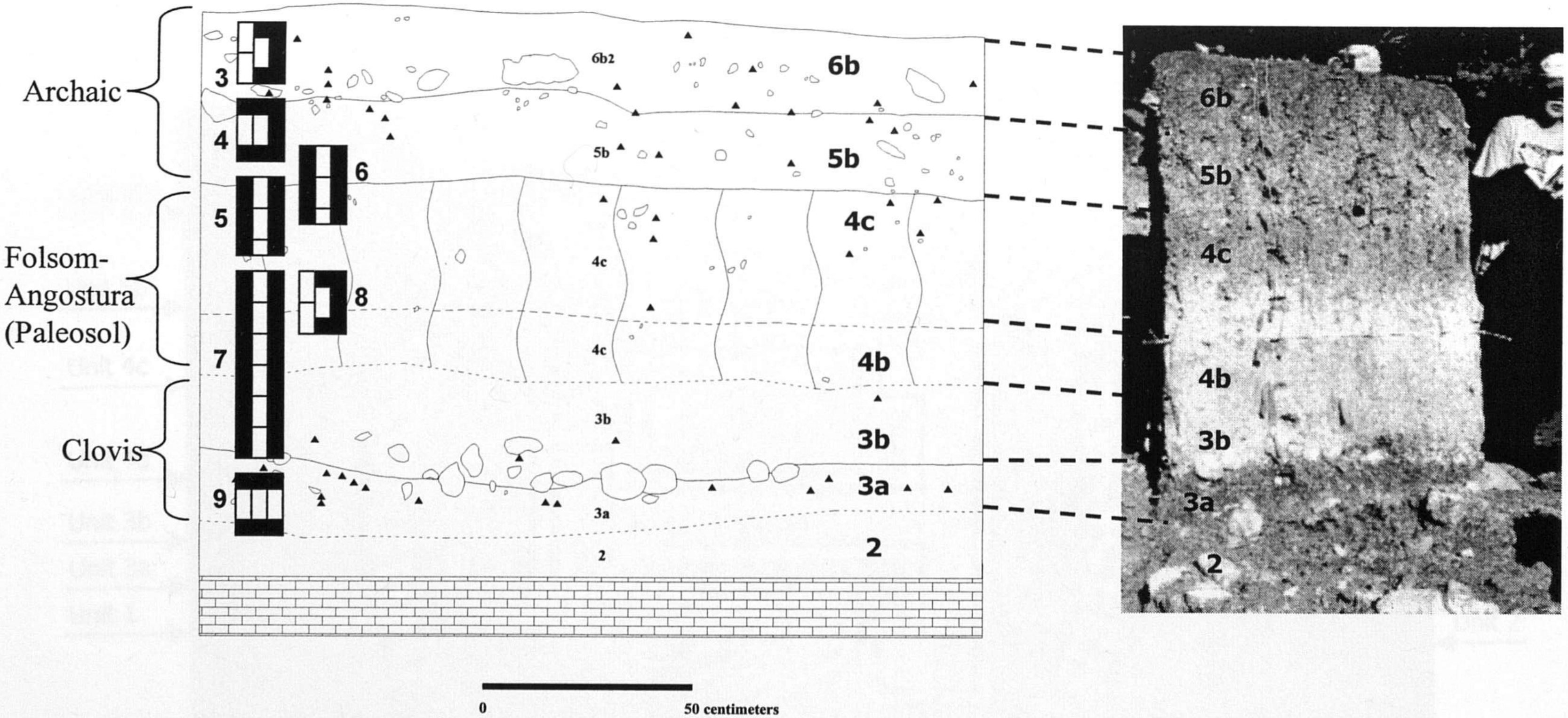


Figure 10. Micromorphological samples taken from sampling location 1 (N1018 E983). Locations of thin sections are designated by the white rectangles within each sediment block. Black triangles represent artifacts and rounded cobbles indicate alluvial and colluvial gravels.

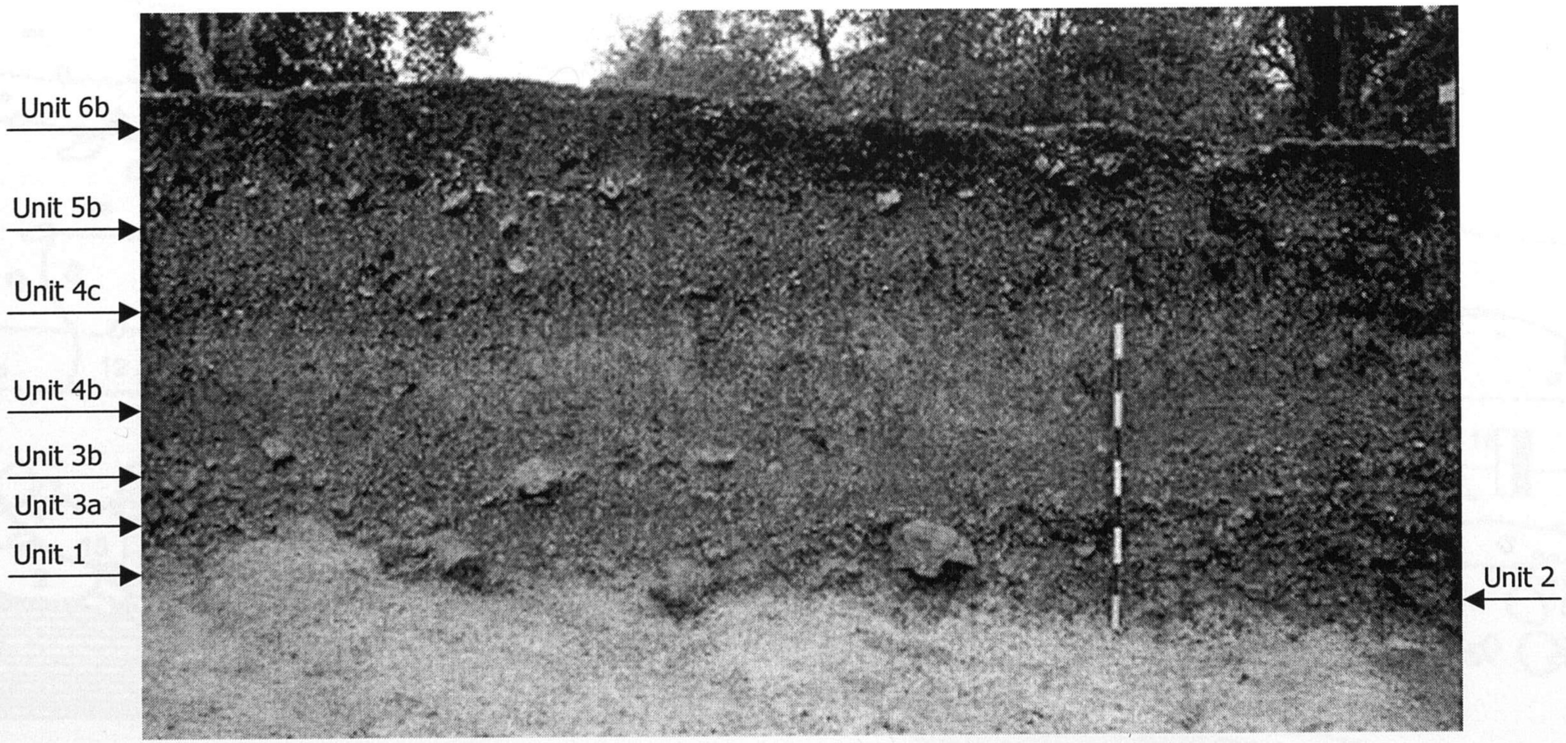


Figure 11. Sampling location 2 of the Texas A&M University excavation block facing east (units N1020 E982 - N1016 E982). The slope increases in the southern part of this profile where colluvial gravels (unit 1) begin to appear and the pond clay of unit 3a pinches out.

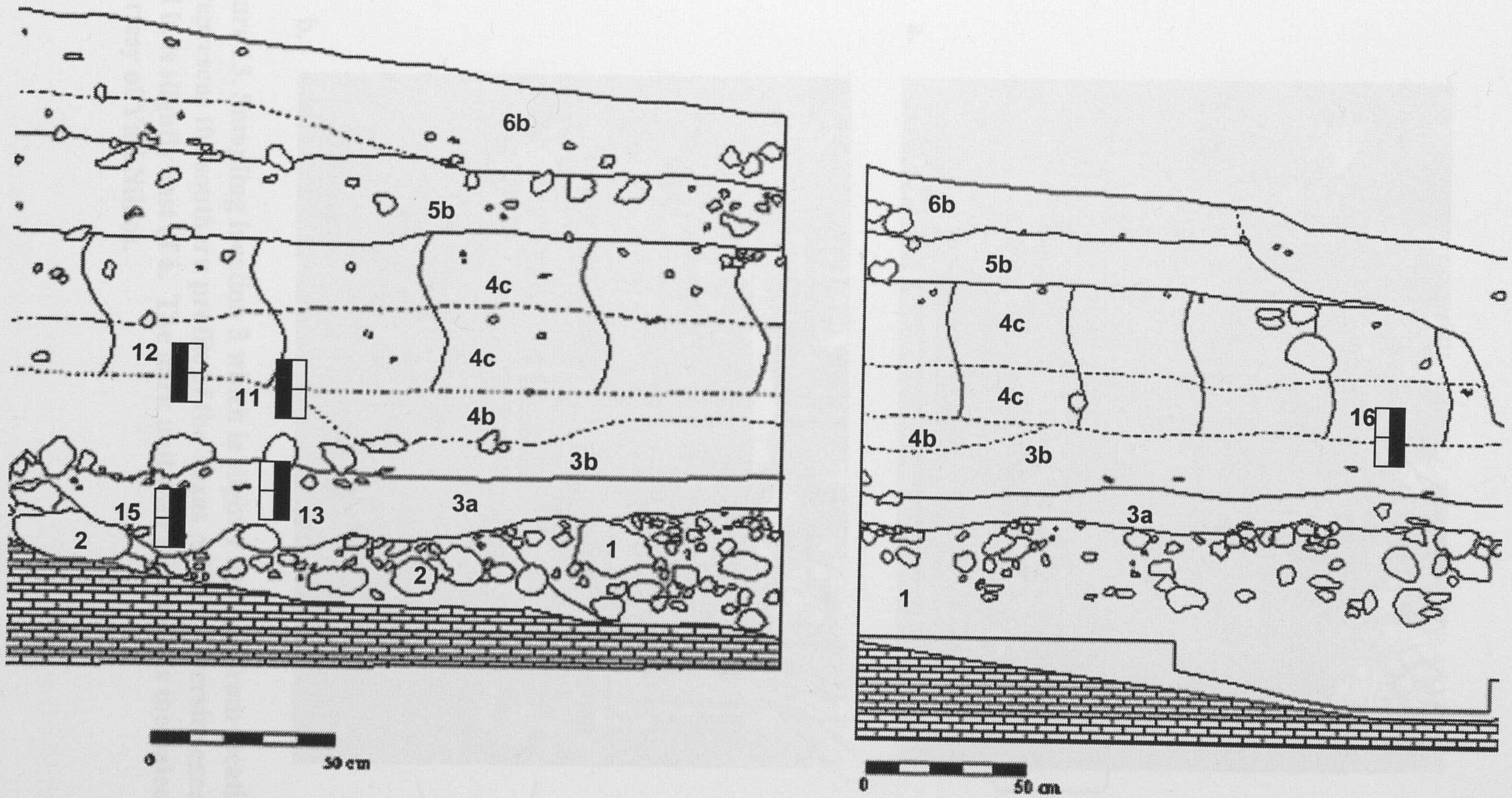


Figure 12. Micromorphological samples from sampling location 2 (N1020 E982 - N1016 E982).

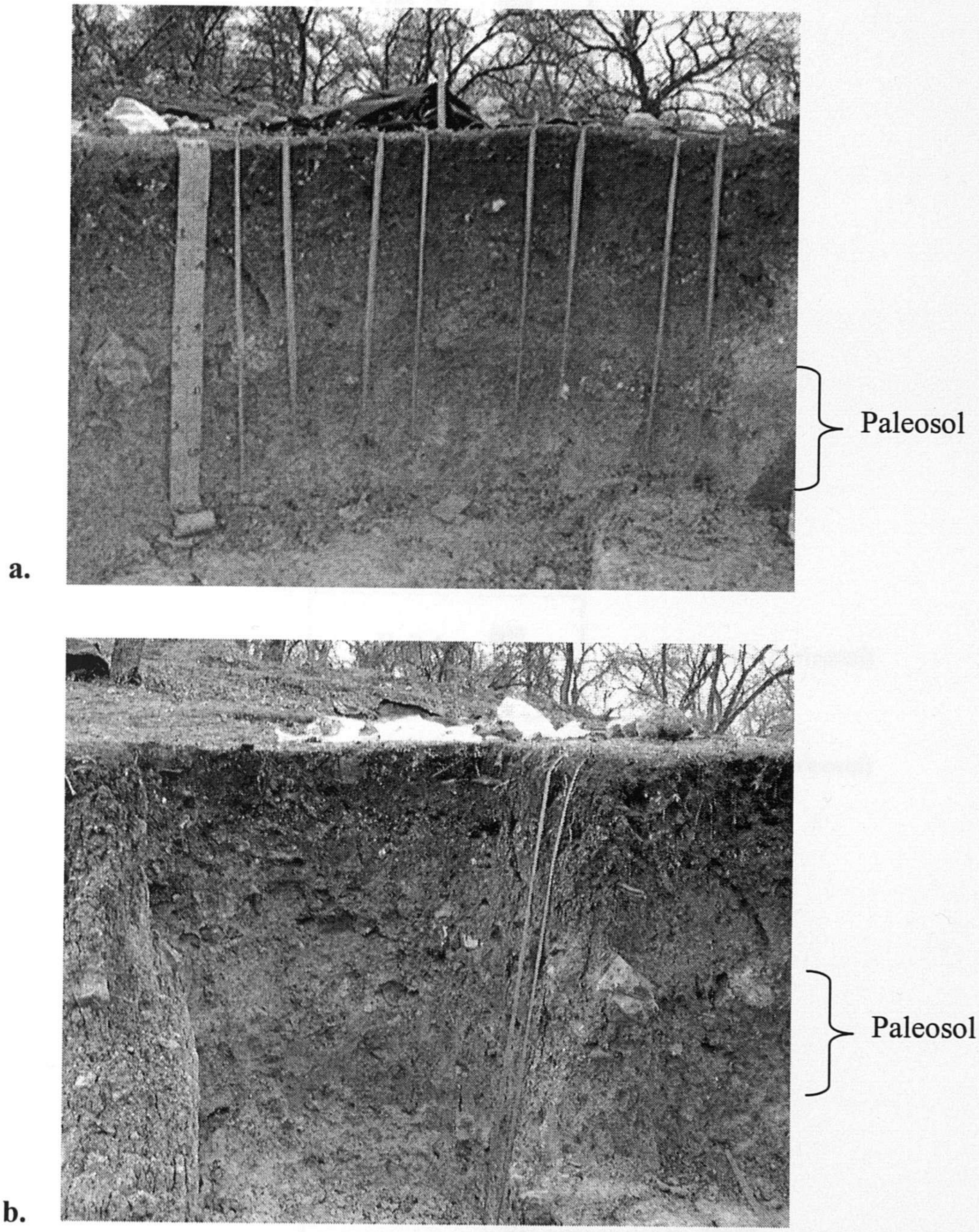


Figure 13. Sampling location 3 which is slightly upslope from location 1. a. and b. represent the southern profile of the Texas A&M University excavation block and b. is slightly east of a. The dark unit with structure is the paleosol (Photos courtesy of Yuji Niino).

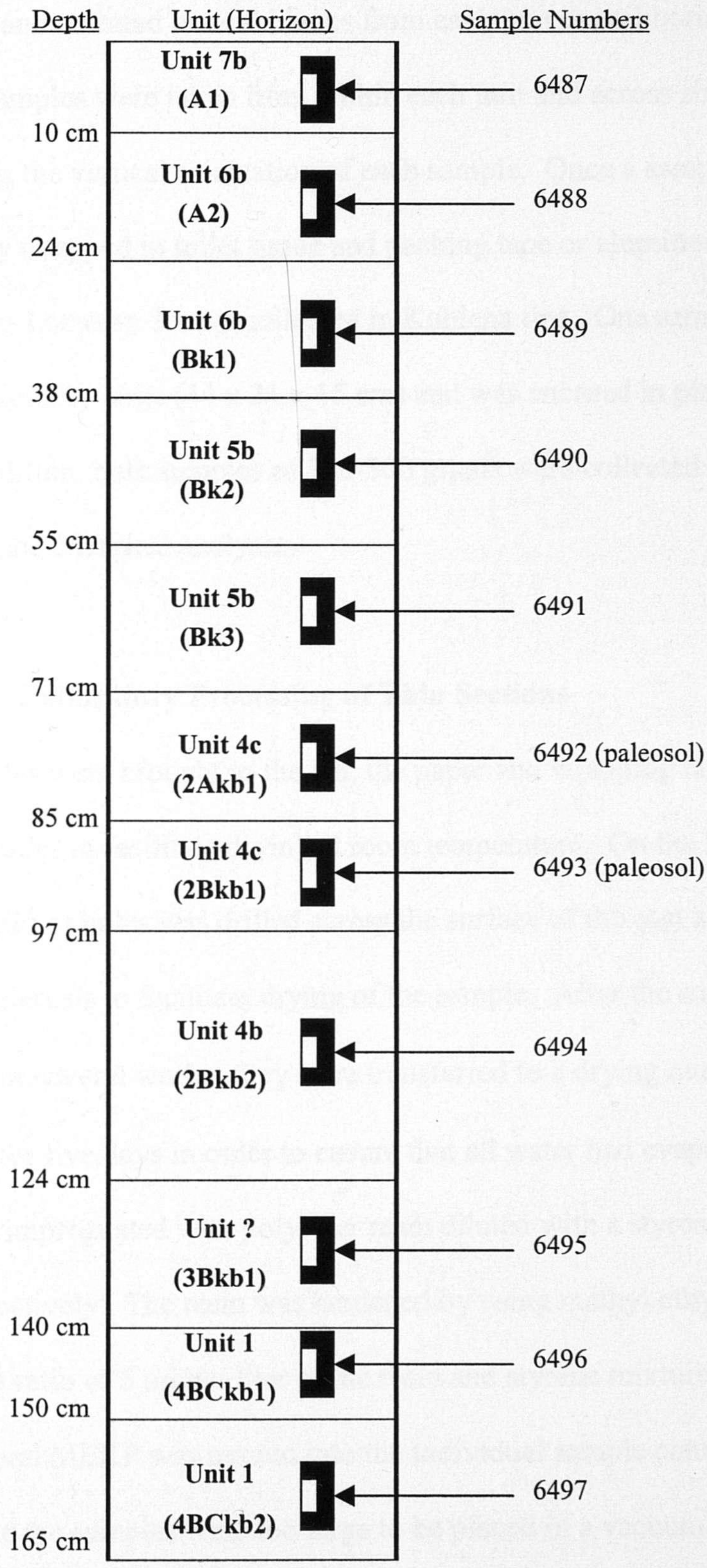


Figure 14. Generalized stratigraphy of sampling location 3 where micromorphological samples were taken.

removing undisturbed and oriented natural blocks from each unit or soil horizon at three sampling locations. Samples were taken from within each unit and across stratigraphic boundaries maintaining the vertical orientation of each sample. Once a sample was collected, it was tightly wrapped in toilet tissue and packing tape or aluminum foil. Samples collected from Location 2 were collected in Kubiena tins. One sample from Location 1 was exceptionally large (34 x 21 x 15 cm) and was encased in plaster before it was removed. In addition, bulk samples of 250-300 grams were collected from each unit for later physical and chemical analyses.

Laboratory Processing of Thin Sections

Once the samples were brought to the lab, the paper and wrapping tape were carefully removed in order to facilitate drying at room temperature. On the large sample encased in plaster, a grid of holes was drilled across the surface of the cast at approximately 3 cm intervals to facilitate drying of the sample. After the samples dried at room temperature for several weeks, they were transferred to a drying oven at 40° C, where they remained for five days in order to ensure that all water had evaporated.

Samples were impregnated with polyester resin diluted with a styrene monomer at a ratio of 7:3, respectively. The resin was hardened by using methyl ethyl ketone peroxide (MEKP) at a ratio of 5 ml per liter of the resin and styrene mixture. A solution of resin with styrene and MEKP was poured into the individual sample containers under a fume hood. Because the samples were too large to be placed in a vacuum chamber during this stage, they were impregnated through a "wicking up" process of capillary action. Once fully impregnated with resin, the samples were left for several days to gel. After the samples had fully gelled, they were placed into a drying oven at 40°C for two to five days to harden.

The hardened samples were then cut with a diamond-edge rock saw using oil coolant to avoid expansion of clays. After cutting to size, oil was removed from the samples by cleaning the surface with ethyl alcohol and placing them on a warming plate for several minutes. These cut sections were then mounted on 2" x 3" glass slides (processed by Spectrum Petrographics, Inc., Winston, Oregon) and ground to a uniform thickness of 30 microns.

Thin Section Analysis

Thin sections were studied at several levels of magnification: first by analyzing hand specimens, then by using a microfiche reader (15X), binocular microscope (20X), and finally a petrographic microscope (40-200X). Under the petrographic microscope samples were viewed under both plane-polarized light (PPL), cross-polarized light (XPL), and reflected light. The composition (mineral and organic), texture (size and sorting), fabric, and microstratigraphy of each thin section were described. Terminology of Bullock et al. (1985) and Courty et al. (1989) were used as these are the standard teminologies used for micromorphological analysis at archaeological sites. Detailed descriptions of each thin section are found in Appendix C.

Components of each sample were identified and characterized. Minerals were identified in plane-polarized light by their color, pleochroism, crystal form, shape, size, cleavage, fracture, refractive index, and relief. Minerals in cross-polarized light were studied by their isotropism, interference color, extinction, and twinning. Reflected light was used in identifying organic matter. Other skeleton grains included lithorelicts, fossils, shell fragments, and archaeological debitage. This study considered skeleton grains by their size, shape, frequency, and sorting; plasmic fabric by distribution and orientation patterns; voids by their shape, size, arrangement, and type; and coatings by their location, mineralogical composition, and internal fabric.

Particle Size Analysis

Particle size analysis was performed on the fine fraction (< 2 mm) as detailed by Hallmark et al., 1986. Bulk sediment samples taken from each stratigraphic unit from the field were poured into plastic containers and dried at room temperature. After several weeks, coarse fragments and visible artifacts were removed and samples were ground and passed through a 2 mm diameter sieve. All coarse fragments > 2 mm were placed in an envelope for future reference.

Next, 10 g of sediment from each sample was placed in numbered sedimentation bottles. The bottles were filled approximately two-thirds full with distilled water and 5 ml of 10% sodium hexametaphosphate was added to each bottle. Bottles were sealed and placed in a reciprocating shaker for 8 hours. Next, distilled water was added to each bottle until the total volume was the equivalent of 400 ml. A magnetic stirring bar was then placed in each bottle and they were stirred for 2 minutes. Pipetting for 20 μm, 2 μm, and 0.2 μm fractions began based on the sedimentation period for collecting each fraction. Pipetted fractions were placed into tared crucibles and the 0.2 μm fraction pipetting was taken from samples that were centrifuged for a period of time based on the temperature of the suspension. The tared crucibles were placed in an oven to dry at 105° C overnight and were weighed to 0.0001 g.

Sediment remaining in the bottles following the pipetting was washed through a 300 mesh (50 μm) sieve until only sands remained. Sands were transferred to a glass beaker and dried overnight in a 105° C oven. Once all water was removed from the beakers, the sands were passed through a nest of five sieves: #18 (1.0 mm), #35 (0.5 mm), #60 (0.25 mm), #140 (0.10 mm), and #300 (0.05 mm). The dry sands were shaken for approximately 5 minutes in the nested sieves, after which each sand fraction was weighed to 0.001 g. All particle size analysis data are listed in Appendix B in terms of sand (2.0-0.05 mm), silt (0.05-0.002 mm), and clay (<0.002).

Pretreatment for Particle Size Analysis Samples:
Dialysis for Destroying Calcium Carbonate

Due to the abundance of calcium carbonate noted in the field and seen in thin section, another set of samples was pretreated for carbonate removal before running the samples for particle size analysis to search for discrepancies. Carbonates were removed from samples following the procedure in Rabenhorst and Wilding (1984). Eight samples were selected to represent every stratigraphic unit.

Samples were ground, sieved through a 2 mm sieve, and measured out for their specific pretreatment weight. The gasometric determination of calcium carbonate percentage (Hallmark et al. 1986) was used to determine how much pretreated sample was necessary to attain at least 10 g of non-carbonate residue for particle size analysis.

Pretreated samples were weighed and placed in a 25-30 cm section of dialysis tubing that was sealed at one end. Each tube was filled approximately half full of a solution of 1 M NaOAc buffered at a pH of 4.5 with acetic acid (Rabenhorst and Wilding 1984). Upon contact with this acid, calcium carbonate particles began to dissolve and gas bubbles were released. Each tube was left open at one end to allow gas to be released and tubes were suspended in a solution of 1 M NaOAc buffered at a pH of 4.5 with acetic acid for 2 weeks. The pH of this solution was measured on a daily basis and acetic acid was added to the solution in order to maintain a pH of 4.5. This helped expedite calcium carbonate dissolution and removal.

Total removal of carbonates was determined after a period of time when gas bubbles were no longer released. The dialysis bags were then soaked in a solution of distilled water for several days to remove salts accumulated during the pretreatment procedure. Samples were then washed into sedimentation bottles using distilled water and the above described procedure for particle size analysis was used. All particle size analysis data for samples on a carbonate-free basis are found in Appendix B.

CHAPTER IV

RESULTS

Analysis of Particle Size Analysis Data

Particle size analysis was conducted to characterize sediments of the Texas A&M University excavation block and this data can be found in Appendix B. Data from each stratigraphic unit (except for unit 7b) is illustrated in a graph in Figure 15 and is plotted with the calcium carbonate equivalent for each unit. As a result of particle size analysis, each sediment was classified as a clay, silty clay, or clay loam due to differences in size fractions (i.e., sand, silt, or clay) between stratigraphic units. The differences in texture between each unit is not dramatic however, as illustrated in Figure 15, the percentage of calcium carbonate fluctuates significantly between units from 3% in unit 3a to 47% in unit 4b. Calcium carbonate can move throughout a system through leaching and precipitation. Therefore, calcium carbonate can affect the results of particle size analysis because it is included in the processing of a non-carbonate-free sample and is represented in the three particle size classes. The Gault site comprises of sediments that are significantly carbonaceous. Therefore, it was necessary to process another set of samples on a carbonate-free basis in order to analyze the non-carbonate fraction of each unit. These results are also located in Appendix B.

The results of particle size analysis on a carbonate-free basis are illustrated in Figure 16. This graph shows that once the calcium carbonate was removed from these samples, the fluctuations in particle-size between units is much less significant

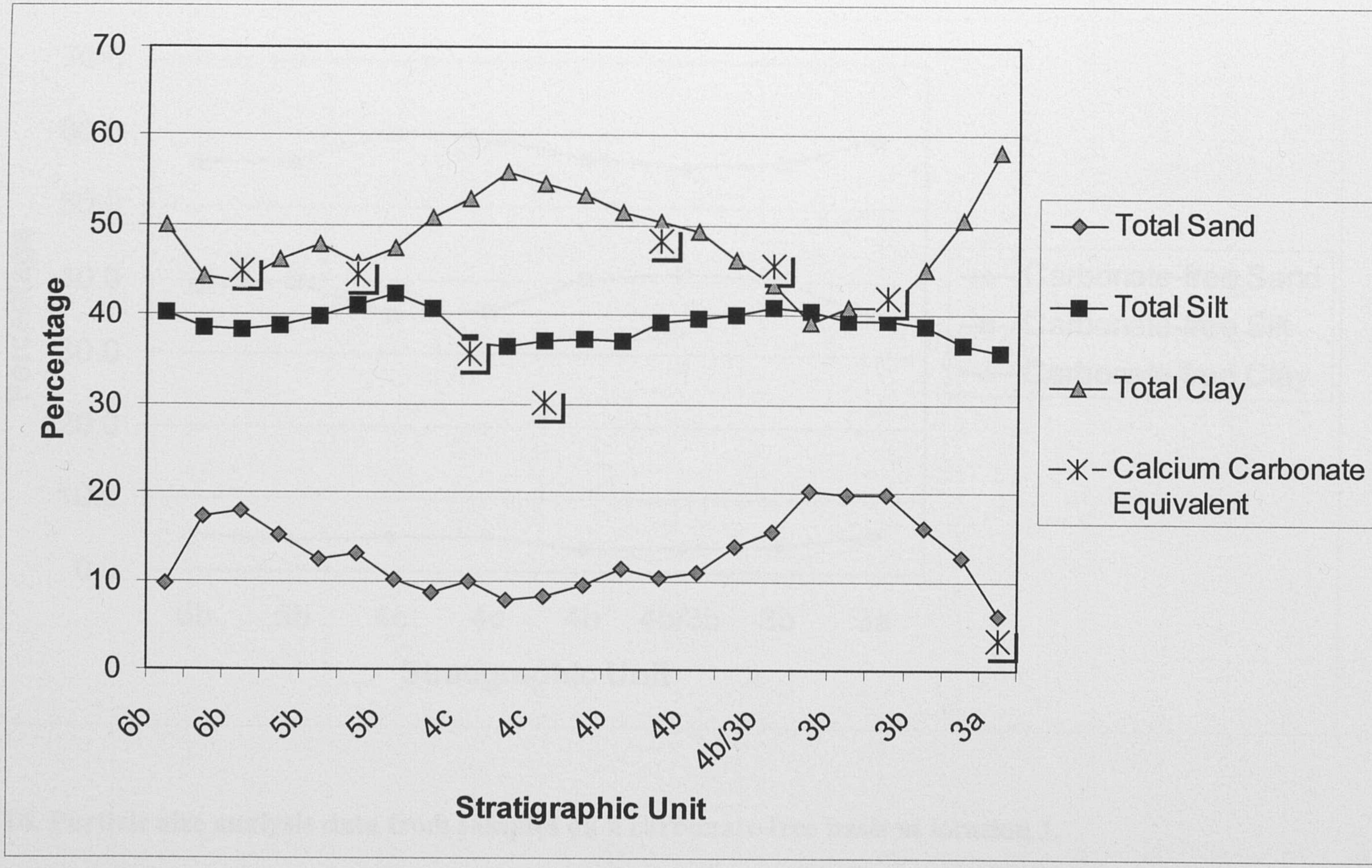


Figure 15. Particle size analysis data from samples on a non-carbonate-free basis at location 1 in addition to the calcium carbonate equivalent for each unit.

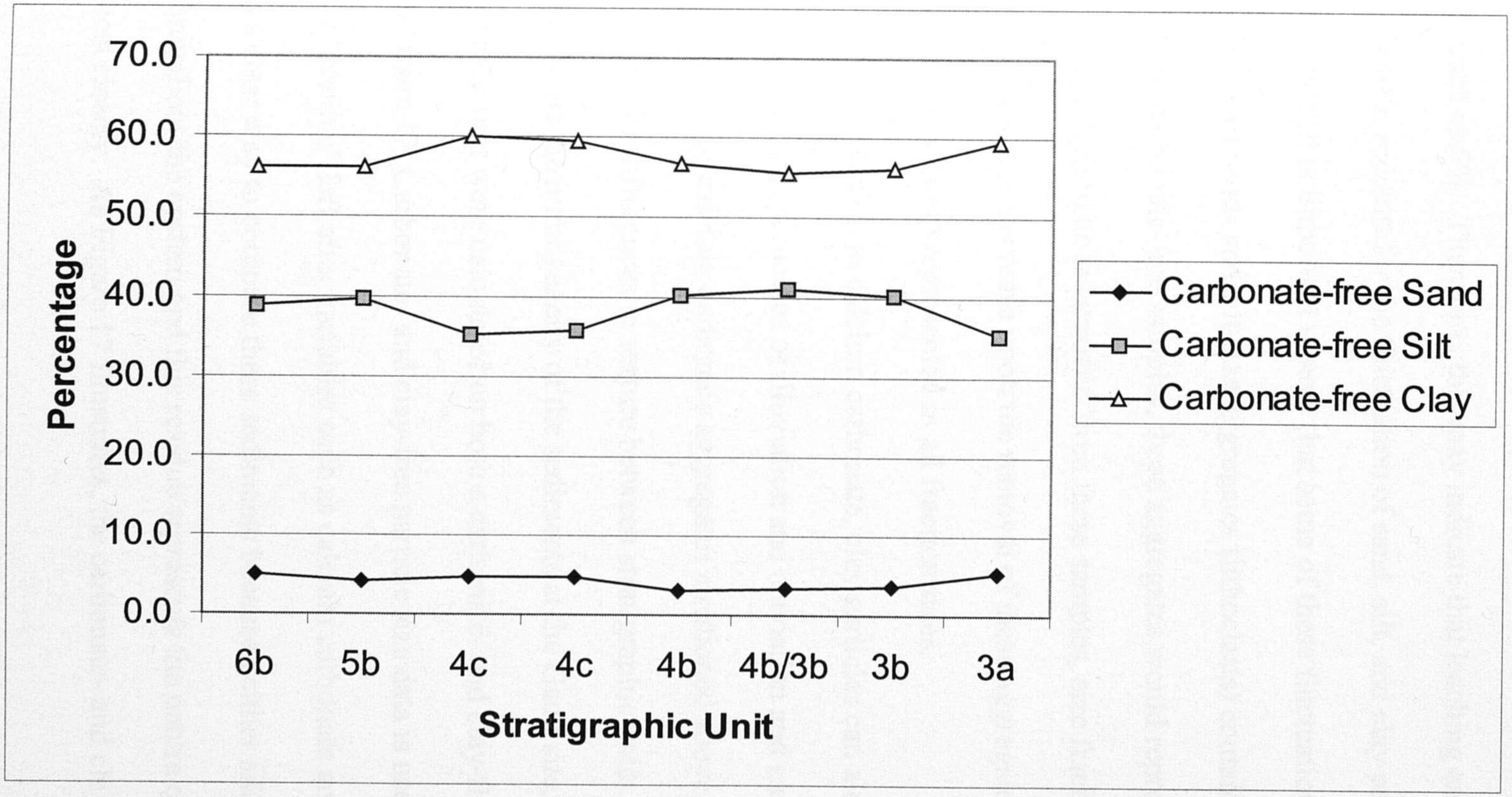


Figure 16. Particle size analysis data from samples on a carbonate-free basis at location 1.

than the non-carbonate-free samples (Figure 15). Non-carbonate-free size fractions may fluctuate as much as 10% between units but carbonate-free size fractions fluctuate only as much as 5%. Therefore, this may indicate that leaching and precipitation of calcium carbonate account for the fluctuation of sand, silt, and clay percentages between units. However, it is important to note that some of these fluctuations could also be due to the presence of sand- and silt-size aggregates (lithoclasts) containing calcium carbonate. In the non-carbonate-free samples, these aggregates would represent sand or silt fractions. Once the carbonate is removed from these samples, size fractions that contained these aggregates may decrease upon the removal of these aggregates. Therefore, calcium carbonate is likely represented in all fraction sizes.

In addition to calcium carbonate, clay particles can also move throughout a system through processes of illuviation and eluviation and can also form aggregates similar to the calcium carbonate aggregates mentioned above. Therefore, clay can also account for differences in texture between stratigraphic units. Moreover, in order to determine the homogeneity of the sediments at the Gault site, the silt and sand fractions for each unit were calculated on both a carbonate- and clay-free basis and are illustrated in Figure 17. Carbonate- and clay-free particle size data is useful because it represents the "residue" left after variables such as calcium carbonate and clay are removed. This is a clear way to compare these sediments because neither silt nor sand can move throughout the system and this residue represents the nature of the original sediment most closely. As Figure 17 illustrates, the carbonate- and clay-free sand and silt

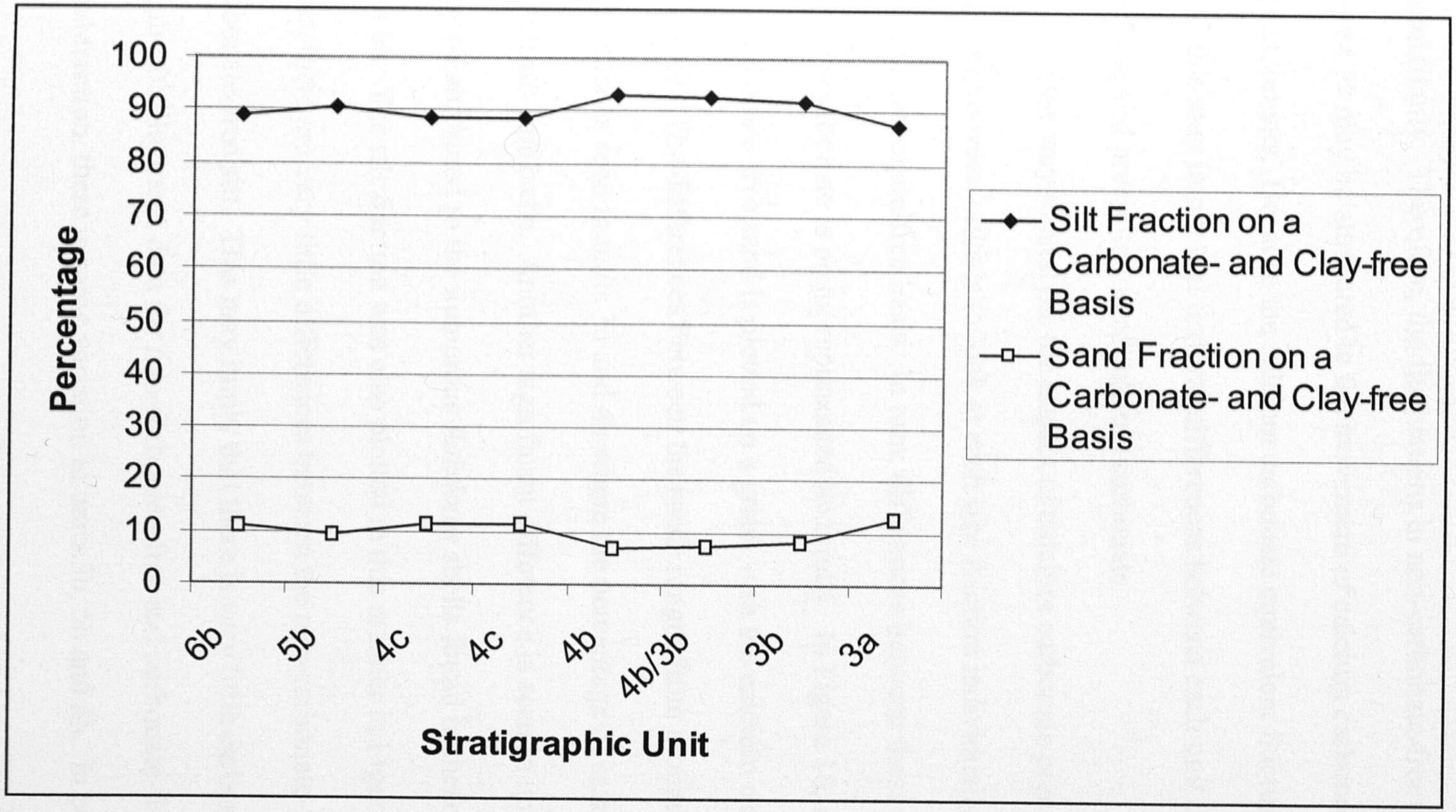


Figure 17. Particle size analysis data from samples on a carbonate- and clay-free basis at location 1.

fractions are very homogenous between units. Each unit varies less than 3-4% which further indicates a common sediment source and no evidence for a lithologic discontinuity. Therefore, the fluctuations in non-carbonate-free samples as illustrated in Figure 15 may be attributed to the movement of calcium carbonate and clay in the Gault site sediments. Because the calcium carbonate equivalent fluctuates more greatly than clay, this may imply that textural differences between each unit is the result of the leaching and precipitation of calcium carbonate.

One way to analyze the impact of calcium carbonate precipitation on textural changes between units is to look at each size fraction individually on a non-carbonate-free and carbonate-free basis. In turn, differences between these data may clarify where calcium carbonate is being represented texturally. In Figure 18, non-carbonate-free sand and carbonate-free sand is plotted on a graph with the calcium carbonate equivalent for each unit. The differences between the sands ranges from around 4-15%. The greatest difference is seen in units 3b and 4b where the percentage of sand decreases on a carbonate-free basis. Another significant difference is seen in units 5b and 6b but this may be attributed to the numerous *Rabdotus* shells found in these units, particularly in unit 6b. The silt fraction was also plotted in this manner in Figure 19. In contrast to the sand, there are very little differences between the non-carbonate-free silt and the carbonate-free silt. This may imply that there is very little carbonate in the silt fraction. Figure 20 illustrates data for non-carbonate-free and carbonate-free clay. Similar to the sand fraction, there is some variation in units 3b, 5b and 6b. In contrast to the sand

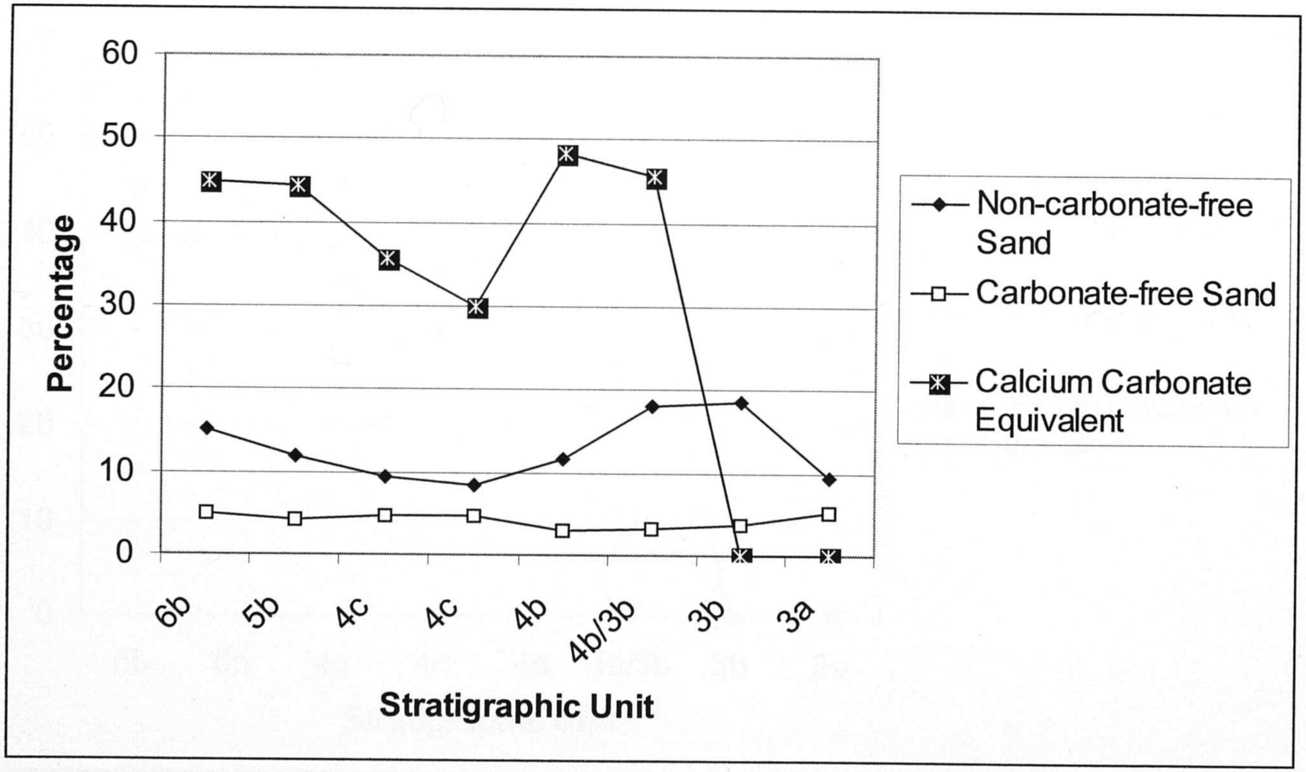


Figure 18. Sand fraction data from samples on a non-carbonate-free and carbonate-free basis at location 1 in addition to the calcium carbonate equivalent for each unit.

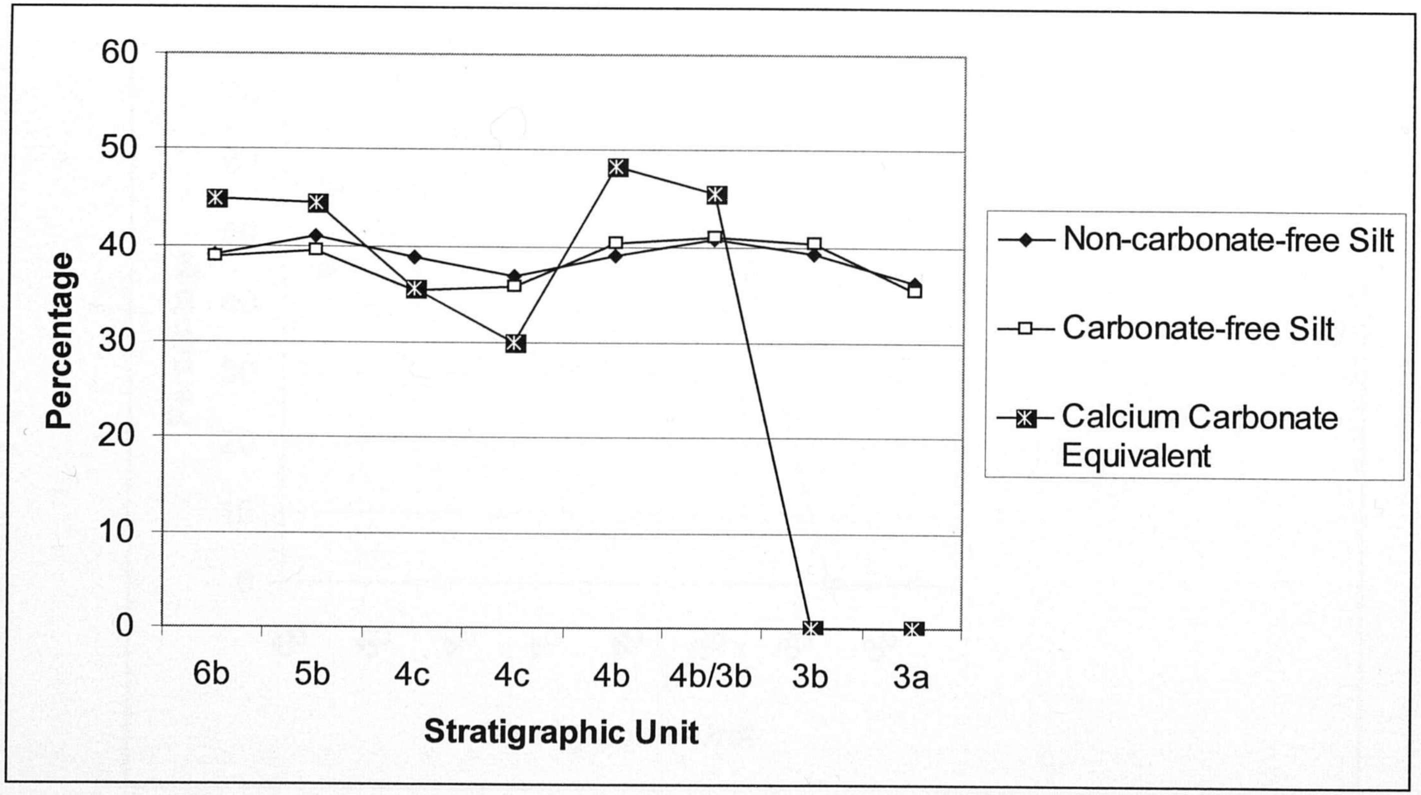


Figure 19. Silt fraction data from samples on a non-carbonate-free and carbonate-free basis at location 1 in addition to the calcium carbonate equivalent for each unit.

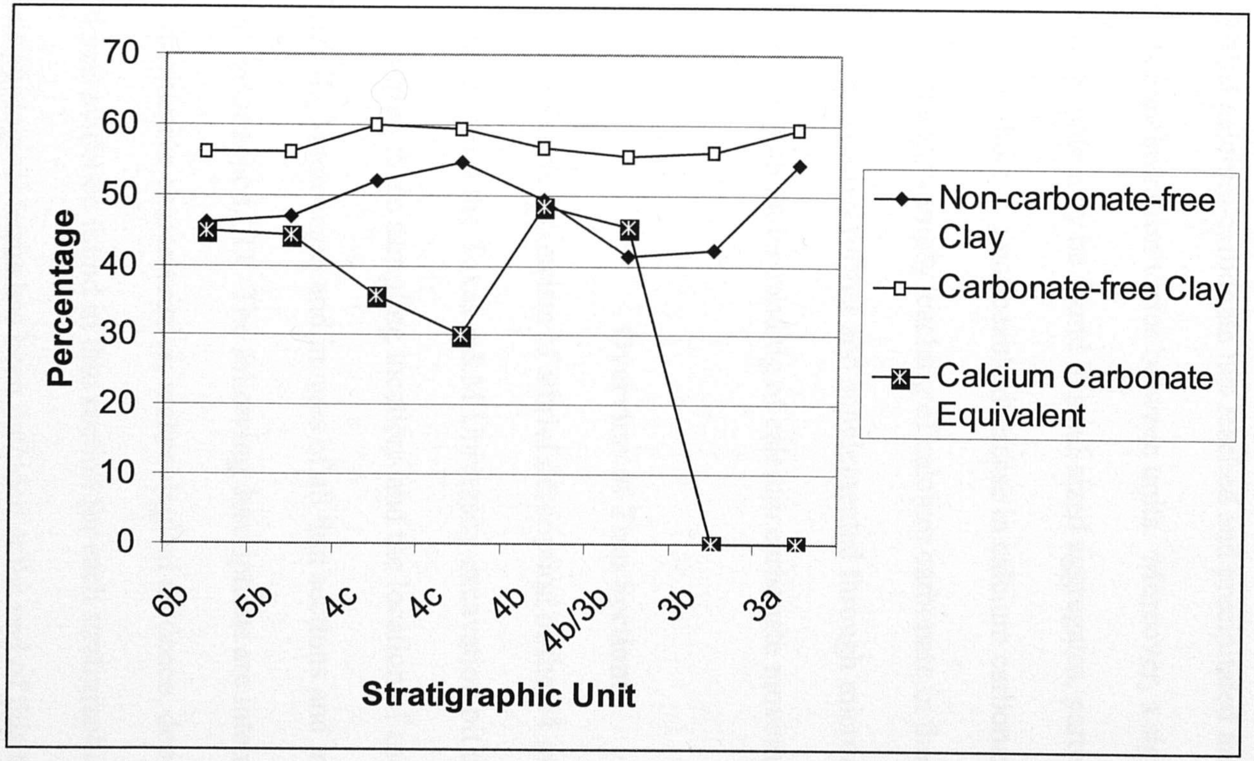


Figure 20. Clay fraction data from samples on a non-carbonate-free and carbonate-free basis at location 1 in addition to the calcium carbonate equivalent for each unit.

fraction, the percentage of clay increases on a carbonate-free basis and this may be the result of the decrease in sand on a carbonate-free basis.

As a result, analysis of the particle size data from sediments at the Gault site may illustrate that calcium carbonate has leached and precipitated throughout these units because its concentration varies between units. Moreover, a significant amount of calcium carbonate may be found in sand-sized aggregates, particularly in units 3b and 4b. Likewise, there is a noticeable decrease in calcium carbonate equivalent in unit 4c and unit 3a that may imply leaching of calcium carbonate in these units. In turn, these issues can be explored further and supplemented through micromorphological analysis in order to reach an understanding of calcium carbonate movement in these sediments.

Overview of Thin Sections

This overview consists of a brief description of the 44 micromorphological samples taken from the Texas A&M University excavation pit at the Gault site. Samples were taken from three sampling locations and the location of each sample can be found in Chapter II. Macroscans and images of all thin sections and impregnated blocks can be found on the attached CD. The following descriptions are intended to explain the general qualitative characteristics, archaeological evidence, depositional, and post-depositional evidence found in thin section for each stratigraphic unit. A glossary of micromorphological terms has been included at the end of this thesis and is intended to supplement this chapter for those not familiar with this type of analysis. More comprehensive descriptions of each thin section are in Appendix C.

Unit 1

This unit was represented by samples from horizon 4BCkb2 (Thin Section 6497) and Horizon 4BCkb (Thin Section 6496) at sampling location 3. Unit 1 consists of decomposing limestone mixed with colluvial gravels. The thin section from this unit has a very fine matrix with porphyric related distribution. There are few mineral grains and a few sand-sized clasts of quartz, calcite, chert, and limestone in addition to fossil and shell fragments. Most clasts are rounded although there are a few angular chert grains. Few dark orange redox concentrations are found in the matrix and on carbonate nodules, fossils, and angular chert fragments. Biological activity is evident by disconnected voids and channels. Carbonate nodules are difficult to distinguish from the calcium carbonate throughout the matrix. One-half of thin section 6496 was treated with acid (HCl) in order to remove carbonates. In thin section, there is a marked difference in the appearance of the matrix under cross-polarized light and it is nearly all dissolved, signifying a high concentration of calcium carbonate in the matrix.

Unit ?

This unit is directly above unit 1 in sampling location 3 and is represented by Horizon 3Bkb (Thin Section 6495). It has not been categorized as one of the main 9 stratigraphic units because its characteristics are not definitive. This sample shares characteristics with unit 1 and overlying unit 4b. Unit 3 is not represented in sampling location 3 and there this sample is not classified as part of this unit. It is possible that the sample was taken at a transitional boundary between units 1 and 4c.

Thin section 6495 contains rounded quartz, angular calcite, angular chalcedony, angular chert, rounded limestone, fossil, and shell fragments. The related distribution is porphyric. Redox concentrations are dark orange and found in the matrix, within carbonates, and on limestone, chert, and chalcedony grains. Disconnected voids and channels indicate evidence of biological activity. Carbonate nodules located in the matrix have both sharp and diffuse boundaries. Calcareous coatings are also present. Thin section 6495 was also treated with HCl to remove carbonates. As a result, it was possible to see a significant amount of fine quartz and much of the matrix dissolved implying that a large amount of the matrix was made up of calcium carbonate.

Unit 3a

Unit 3a was sampled at sampling location 1 (thin sections 9A, 9B, 9C) and sampling location 2 (thin sections 13.1, 13.2, 15.1, 15.2). This fine clay matrix contains few grains of quartz, calcite, chert, chalcedony, and limestone with porphyric related distribution. Quartz and limestone grains are rounded. Grains of calcite and chert are found both rounded and angular. Quartz is mainly silt- to sand-sized and found throughout the matrix. Voids found in these samples include channels, vesicles, vughs, and chambers. Orange redoximorphic concentrations with diffuse boundaries are found scattered throughout the matrix and on limestone grains. Striated b-fabric is strongly oriented along macropores (porostriated), skeleton grains (granostriated), and at angles within the matrix (cross-striated). Disconnected voids indicate that this sediment has been moderately disturbed by biological activity. Calcium carbonate nodules are found throughout the matrix and along macropores, with sharp and diffuse boundaries.

In sampling location 2, the fabric of unit 3a is more spongy compared with sampling location 1. It also has dark orange iron staining in the matrix and fine quartz scattered throughout. Some carbonate nodules are fairly large and are in the process of breaking into smaller nodules. There is one chert flake and several modern roots. Compared to thin sections 13.1 and 13.2, carbonate nodules are not as iron-stained and the fabric is not as spongy in thin sections 15.1 and 15.2

Unit 3b

Unit 3b (silty-clay to clay) is best represented in sampling location 2 by thin sections 12.1 and 12.2. In thin section, unit 3b is less clayey than unit 3a. Archaeological evidence was also found in unit 3b in the form of chert flakes and a possible bone or tooth. The boundary between units 3b and 4 was difficult to gauge in the field in both sampling locations 1 and 2. Although unit 3b may also be represented in the lower portions of samples 11 and 16 (thin sections 11.2 and 16.2) in sampling location 2, they are not definitively categorized as part of unit 3b. Likewise, thin sections 7E and 7F from sampling location 1 may also be part of unit 3b or the boundary between units 3b and 4b.

Thin Sections 11.1 and 11.2 have a fine matrix with redoximorphic concentrations that are fairly diffused within the matrix. The microstructure appears spongy and very few large clasts are present. In thin Sections 16.1 and 16.2, the matrix is fairly calcareous. Some carbonates are stained with iron and others are possibly stained by manganese. Carbonates increase in concentration in thin section 16.2 which comes from the lower portion of sample block 16. A possible piece of charcoal was seen in thin section 16.1.

Thin sections 7E and 7F contained rounded grains of quartz, calcite, chert, chalcedony, and limestone and have porphyric related distribution. Some chert grains were large and angular fragments and some limestone grains are iron-stained. Most of the quartz appears to be silt-sized. Voids include channels, vesicles, vughs, and chambers and disconnected voids indicate moderate biological activity in this unit. Redoximorphic concentrations are present in the matrix with diffuse boundaries. Orthic carbonate nodules are found throughout the matrix and along macropores with both sharp and diffuse boundaries. Compared to thin sections 7E and 7F, the matrix in thin sections 12.1 and 12.2 is more uniform and finer. In turn, thin section 7F is clayier and more coarse.

Unit 4b

Unit 4b is most clearly represented in Horizon 2Bkb2 (Thin Section 6494) from sampling location 3. The related distribution of this sample is porphyric and contains rounded grains of quartz, calcite, chalcedony, chert, and limestone, and is poorly sorted. Some chert grains are angular. Voids are found in the shapes of channels, vesicles, vughs, and chambers and biological activity is evident from some voids which are disconnected. Redox concentrations are dark orange and seem concentrated both within pedogenic carbonates, the matrix, and some iron staining also appears on limestone and chert fragments. Carbonate nodules are found in the matrix with diffuse boundaries, but many carbonate nodules have dissolution holes in the center. Carbonate coatings are also present.

Unit 4c

Unit 4c was sampled at location 1 (thin sections 7A, 7B, 7C, 7D, 5A, 5B, and 5C) and location 3 (Horizon 2Bkb1, thin section 6493; and Horizon 2Akb, thin section 6492) and is well represented in most areas across the site. In thin sections unit 4c has a clay matrix that contains few grains in the matrix (porphyric related distribution). Grains present in this sample include rounded quartz, calcite, chert, chalcedony, limestone, and a shell fragment. Some chert fragments are angular. Fine, silt-sized quartz grains are distributed throughout the matrix. The types of voids found in this sample include channels, vesicles, vughs, and chambers. Channel voids in this fabric are oriented mainly perpendicular to the surface and the presence of disconnected voids indicates moderate biological activity. Redoximorphic concentrations found in the matrix and along macropores have diffuse boundaries and are dark orange to dark orange-red. Calcium carbonate nodules found throughout the matrix and along macropores have both sharp and diffuse boundaries. Compared to thin sections 7E and 7F, there are fewer grains in thin sections 7C and 7D. Redoximorphic concentrations are more concentrated in thin sections 7E and 7F (unit 3b/lower portion of unit 4b) than in thin sections 7A, 7B, 7C, and 7D. In addition, redox concentrations appear to be more concentrated in thin section 7C than in overlying thin section 7B.

Thin sections 5A, 5B, and 5C represent the uppermost portion of unit 4c where the paleosol is the most developed and thin sections 6A, 6B, and 6C cross the boundary between units 4c and 5b. Once again, the boundary between units 4c and 5b was not micromorphologically definitive so thin sections 6A, 6B, and 6C share characteristics of both units. The clay matrix of unit 4c appears darker than the overlying and underlying units. This may be attributed to a higher amount of organic matter as this unit is part of the paleosol. The mineralogy of these thin sections is characteristic of unit 4c (rounded grains of quartz, calcite, chert, chalcedony, and limestone) although some chert fragments are angular. Limestone and chalcedony clasts are reddened by iron staining and fine silt-sized quartz is distributed throughout the matrix. Voids include channels, vesicles, vughs, chambers, and some parts of the fabric are spongy. Disconnected voids indicate moderate biological activity. Redoximorphic concentrations found throughout the matrix are dark orange-yellow and have diffuse boundaries. Orthic calcium carbonate nodules have both sharp and diffuse boundaries and are distributed throughout the matrix and along macropores.

Unit 5b

Unit 5b is represented by thin sections 4A and 4B from sampling location 1 and Horizon Bk3 (Thin Section 6491) and Horizon Bk2 (Thin Section 6490) from sampling location 3. Grains included are rounded quartz, calcite, chert, chalcedony, and limestone inclusions although one grain of chert is angular (porphyric related distribution). The limestone also shows some reddening due to iron staining and silt-sized quartz is distributed throughout the matrix. Channels, vesicles, vughs, and chambers appear throughout the matrix. Orange redox concentrations are present in the form of masses and pore linings although some are also more yellow and dark orange and are found throughout the matrix and along macropores. In addition, iron staining is seen within carbonate nodules. In thin section 6491, redox concentrations in a slightly higher concentration than in thin section 6490 which was taken at a slightly higher location within unit 5b. Some biological activity is evident by disconnected voids. Orthic carbonate nodules are found in the matrix and along macropores with sharp and diffuse boundaries.

Another sample taken from this horizon was also thin sectioned and treated with acid (HCl) to remove carbonates. Many of the same characteristics of the untreated sample were seen in this sample except for a large round grain that was made up of many small grains with radial extinction. In addition, redox concentrations remained where carbonate nodules were located. They are also seen on chert fragments. Angular chert fragments are also present and appear to be archaeological. This removal of carbonates confirmed some of the observations made previously on untreated samples.

Unit 6b

Unit 6b was sampled in locations 1 and 3 and is represented by thin Sections 3A, 3B, 3C (sampling location 1) and Horizon Bk1 (Thin Section 6489) and Horizon A2

(Thin Section 6488) (both from sampling location 3). Unit 6b contains rounded grains of quartz, calcite, chert, chalcedony, and limestone grains in addition to fossil and abundant shell fragments in a porphyric fabric. Most of the chert fragments are angular. Some limestone fragments are reddened with iron and fine quartz appears to be distributed throughout the matrix. Voids include channels, vesicles, vughs, chambers, and planes. Redoximorphic concentrations are common throughout the matrix and along channels. They are dark orange-brown to yellow in color and have diffuse boundaries. Redox concentrations occur along macropores and within pedogenic carbonate nodules. Iron staining also appears on calcite and chert grains. Biological activity is evident from the presence of disconnected voids and there is no orientation of skeleton grains or fabric. Carbonate nodules found in the matrix and along macropores have diffuse boundaries.

In contrast to unit 6b, the matrix of unit 5b appears grainier in thin section. In addition, redox concentrations in unit 6b (thin sections 3A, 3B, and 3C) are darker orange than those found in unit 5b (thin sections 4A and 4B). Redox concentrations found within carbonate nodules is also slightly more frequent in unit 6b than unit 5b. However, in sampling location 3, redox concentrations appear in slightly greater concentration in unit 5b than unit 6b. The matrix of unit 6b is also slightly darker than underlying unit 5b.

Unit 7b

Unit 7b was only sampled in sampling location 3 (Horizon A1 and thin section 6487). This sample was taken from the A horizon of the modern soil that is 10 cm thick. In contrast to unit 6b (shell hash), the matrix of this unit is much darker and grainier. The mineral grains include quartz, chalcedony, calcite, chert, limestone, fossils, and shells (in the lower portion of the sample). Quartz, chalcedony, calcite, chert and limestone are rounded. Voids include channels, vesicles, vughs, chambers, and planes. It also appears spongy and the related distribution is porphyric. Redox concentrations are localized within pedogenic carbonates and there is no orientation of skeleton grains or fabric. Evidence of biological activity is indicated by disconnected voids and channels. The calcium carbonate nodules are fine-grained nodules that do not include grains from the matrix. Some chert is stained. Carbonates with sharp boundaries are found in the matrix. Carbonate coats chert fragments that do not appear to be archaeological.

CHAPTER V

MICROMORPHOLOGICAL INTERPRETATIONS

Micromorphological analysis was guided by four issues raised during analysis of the geoarchaeology at the Gault site. A thorough understanding of these questions was necessary to help clarify the depositional and post-depositional history of the site. The goals of this analysis were to understand: 1) the origin and formation of calcium carbonate features observed in all units during excavation, 2) the impact of groundwater on site sediments, 3) the effects of post-depositional processes on site integrity, and 4) the location of archaeological evidence in thin section that may have not been observed in the field.

Origin, Morphology, and Development of Calcium Carbonate Forms

This section analyzes the origin in the sediments, morphology, and development of calcium carbonate forms. Classification into stages of accumulation will reflect the degree of pedogenesis affecting these sediments and fluctuations in soil moisture contributed by regional climate changes. However, it should be emphasized that this issue will not be resolved conclusively until completion of stable carbon isotope analysis. Micromorphological analysis of these calcium carbonate forms is only intended to complement analysis of the isotopes.

Precipitation of Calcium Carbonate

Analysis of the presence, distribution, and morphology of calcium carbonate forms in a sediment is a good way to consider the impact of groundwater on each stratigraphic unit. Calcium carbonate can become dissolved and redeposited (precipitated) by vadose water or groundwater under particular conditions. Variations in soil pH, carbon dioxide concentration, temperature, and biological activity are significant factors in the dissolution and precipitation of calcium carbonate in a soil (Krauskopf and Bird 1995). Detailed discussions of this chemical process are discussed in Birkland (1999), Drever (1988), Krauskopf and Bird (1995), McFadden et al. (1991), and Wright and Tucker (1991). Formation of calcic and petrocalcic horizons in Central Texas is discussed in Rabenhorst et al. (1991), and Rabenhorst and Wilding (1986 a,b).

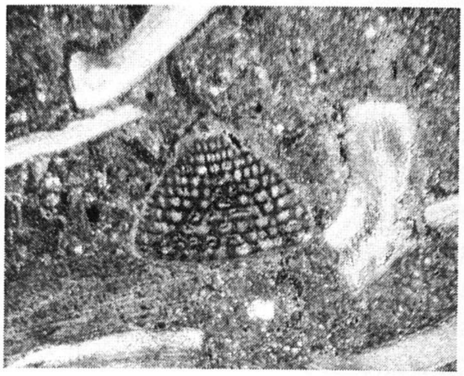
Calcium carbonate goes into solution when a soil has a < 7 pH (acidic), low temperature, high biomass density, or high carbon dioxide concentration. Precipitation of calcium carbonate occurs at > 7 pH (alkaline), high temperature, low biomass density, or low carbon dioxide concentration in the soil (Krauskopf and Bird 1995). Because the processes of dissolution and precipitation reflect fluctuations in these parameters, they may also suggests past climate change.

Summary of Calcium Carbonate Forms at the Gault Site

At the Gault site, both pedogenic and lithogenic (inherited) carbonates were found. Lithogenic carbonates that were inherited from local limestone bedrock and deposited by alluvial or colluvial processes include occasional fossil fragments and fossiliferrous and non-fossiliferrous limestone clasts (Figure 21). Pedogenic carbonates precipitate out of solution in a sediment and evolve into various forms. Pedogenic carbonates are found in all units at the Gault site in the form of filaments, pore coatings, and nodules (Figure 22). Analysis of these carbonates in thin section can help differentiate these carbonates from lithogenic carbonates that may appear similar in the field. Calcium carbonate forms found in each unit are summarized in Table 2.

Stages of Calcium Carbonate Accumulation

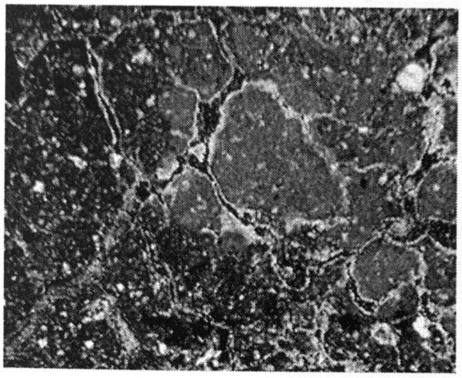
It is necessary to qualify the extent of calcium carbonate accumulation within each stratigraphic unit, which can help illustrate the extent of soil development. Increasing complexity or diversity of carbonate forms indicates that these forms are left over from earlier stages of soil formation or are the product of on going processes (Gile et al. 1981). Soil scientists have devised a system for classifying the accumulation of calcium carbonate in soil profiles into several stages of development (Birkland 1999, Gile et al. 1981, Gile et al. 1966, Machette 1985, and Monger et al. 1991). Gile et al. (1966) first devised a system of classification composed of four stages. This system was expanded to include two additional stages by Machette (1985) based upon fieldwork conducted on soils in the Southwest (Bachman and Machette 1977) and has been further modified by Birkland (1999). Stage I is defined by the most weakly developed calcium carbonate accumulation and Stage VI consists of highly developed calcium carbonate a.



b.

Figure 21. a. Fossil fragment in thin section 3a (Unit 6b). b. Large limestone clast in thin section 3a (Unit 6b). The field for both images is 2.5 mm across and these thin sections are in cross-polarized light.

a.



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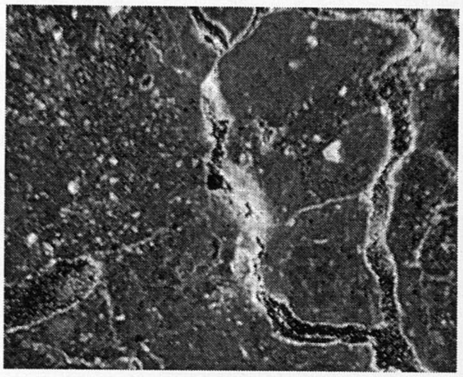


Figure 22. a. Calcium carbonate coating a nodule in thin section 4B (Unit 5b). b. Calcium carbonate infilling of a void in thin section 4B (Unit 5b). The precipitated calcium carbonate has larger grains than fine-grained nodules. The field is 2.5 mm across and in cross-polarized light.

Table 2. Forms of calcium carbonate in thin section. $CaCO_3$ equivalent (%) is based on soil characterization data (see Appendix B).

Unit	$CaCO_3$ Equivalent (%)	Characteristics
6b	45	Calcareous matrix with some fragments of limestone and calcium carbonate nodules. Some nodules are darkly stained with iron and manganese.
5b	44	Calcareous matrix. Increase in carbonate concentration. Calcareous matrix with some fragments of limestone and calcium carbonate nodules. Some nodules are darkly stained with iron and manganese.
4c	33	Calcareous matrix. Drop in carbonate concentration. Calcareous matrix with large compound calcium carbonate nodules that are also stained with manganese and iron. Towards the top of this unit are some fragments of limestone.
4b	47	Calcareous matrix. Abundance and diversity of carbonate forms: infillings, nodules, compound nodules, and coatings. Some large compound calcium carbonate nodules were lightly stained with iron and manganese in the center.
3b	44	Calcareous matrix. Carbonate nodules, infillings, and coating along macrovoids. A few nodules and infillings are lightly stained by iron.
3a	3	Few carbonate nodules, fragments of limestone, and no infillings. Little evidence for carbonate precipitation.

morphologies. Rabenhorst et. al (1991) stages V and VI for Central Texas although they are not represented at the Gault site.

At the Gault site, calcium carbonate accumulation is present from stages I to II+ and has been summarized in Table 3. According to this classification scheme, Unit 3a can be classified as Stage I (low gravel content). Overlying units 3b and 4b have a greater density of secondary calcium carbonate and their characteristics most closely

Table 3. Stages of calcium carbonate accumulation for each stratigraphic unit at the Gault site.

Unit	Stage	$CaCO_3$ Equivalent (%)
7b	I	25
6b	I+	45
5b	I+	44
4c	II	33
4b	II+	47
3b	II+	44
3a	I	3

match stage II+ (low gravel content). Unit 4c is stage II (low gravel content) because its secondary calcium carbonate content drops compared to unit 4b and units 5b and 6b are stage I+. Unit 7b is most likely a stage I with few filaments and nodules.

In summary, secondary calcium carbonate accumulation in unit 3a is very low compared to overlying units. Secondary carbonate appears to increase in units 3b and 4b relative to unit 4c. Accumulation also increases in units 5b and 6b compared to unit 7b of the modern surface. However, regardless of these differences, each of these units consists of similar alluvial sediment originating from a common source (Buttermilk Creek drainage area) which contains similar concentrations of calcium carbonate upon deposition. Therefore, contrasts in secondary calcium carbonate accumulation may be attributed to differential weathering processing that have acted upon each unit. This may indicate that unit 3a has been heavily leached prior to burial. Leaching also appears to have occurred in units 4c resulting in an increase of secondary carbonate in units 4b and 3b. Units 5b and 6b have been moderately weathered but not to the extent of units 3a and 4c. Unit 7b is the youngest sediment represented in the excavation block and its lower concentration of secondary carbonates may be either the result of leaching into lower units 5b and 6b or the requisite time for leaching has not yet occurred.

Distinguishing Pedogenic and Lithogenic (Inherited) Calcium Carbonate Forms

As shown above, calcium carbonate nodules are prevalent in all units of the Gault site. Calcium carbonate can appear in a variety of forms (e.g., limestone clasts and pedogenic nodules and filaments). Some forms are considered lithogenic and inherited from bedrock (e.g., fossils and limestone fragments), while others are pedogenic and formed *in situ* as a result of pedogenesis (pedogenic nodules, filaments, and coatings). It is important to gain a better understanding of the origin of calcium carbonate forms because this will also indicate how extensive soil formation occurred within these sediments as previously discussed.

Pedogenic and lithogenic carbonates can be very difficult to distinguish in thin section (Rabenhorst et al. 1984). One of the main factors is the variability in calcium carbonate morphology in thin section. Pedogenic carbonates found in soils that develop on a non-calcareous parent material are much easier to distinguish because carbonates present in such a soil are most likely formed by pedogenesis (West et al. 1988). Investigation of this issue has been conducted by Drees and Wilding (1987), Rabenhorst, et al. (1984), and West et al. (1988). As a result of their study, West et al. (1988) developed some guidelines for characterizing pedogenic and lithogenic carbonates in the field and in the laboratory (Table 4). These guidelines were carefully considered while analyzing the morphology and origin of calcium carbonate forms in thin sections from the Gault site.

Table 4. Characteristics used for distinguishing pedogenic carbonates from lithogenic carbonates through field and laboratory observation (after West et al. 1988).

Field Observations:

Characteristic	Pedogenic Carbonate	Lithogenic Carbonate
Fossils	--	Present
Form	Soft segregations, nodules, concretions, pendants, laminar caps	Jointed, massive, bedded, oolitic, pisolitic, etc.
Distribution Patterns	Conforms to surface topography, associated with macrovoids	No relation to present surface, topography or macrovoids
Boundary contrast with s-matrix	Sharp to diffuse	Sharp
Topography of horizon boundary	Wavy to irregular	Smooth (planar)
Color contrast with s-matrix	Strong	Weak
Macroporosity	Present	Mostly absent

Observations through Micromorphology and Laboratory Analyses:

Characteristic	Pedogenic Carbonate	Lithogenic Carbonate
Mineralogy	Calcite or high-Mg calcite	Calcite and dolomite, little high-Mg calcite
Grain-size	Dominated by coarse clay and fine silt	No distinctive grain size
Grain-size and mineralogy of residue	Similar to s-matrix	Dependent on carbonate facies
Fossils	None	Present
Skeleton grains	Often occluded	Absent
Fe-Mn staining	Common	Rare
Macroporosity	Abundant	Rare
Cutanic forms	Often present	None
Basic distribution	Banded, clustered or concentric	Undifferentiated
Needles	Common	Rare
Stable C-isotopes	δ^{13}C: -1.3 to –6.4	δ^{13}C: -0.7 to 1.6

As mentioned previously, micromorphological analysis of calcium carbonates should be supplemented with stable C isotope analysis, especially in soils forming over limestone (West et al. 1988). The weakness in methods such as calculating total calcium carbonate equivalent and point counting in thin section is their accuracy in differentiating between the two forms. Calculations of calcium carbonate equivalent does not distinguish pedogenic carbonate from lithogenic carbonate and problems arise in point counting when it is difficult to recognize the two types in thin section (Nordt 1996). By contrast, Stable C isotope analysis is a stronger tool because it can quantify the amount of pedogenic carbonate that has accumulated in a sediment if groundwater has not been involved in their formation. Samples for Stable C isotope analysis have been taken from the Gault site and are currently being processed.

It could be suggested that these calcium carbonate forms are actually produced by groundwater rather than through pedogenesis. Once again, this issue may be resolved more clearly once the stable C isotope analysis has been completed. However, there are some features in thin section that indicate that these carbonates are pedogenic nodules rather than groundwater carbonates. First, the morphology of these carbonates can be classified according to the established stages of accumulation discussed earlier. Second, the distribution and concentration differences between units reflects weathering by leaching that occurs during pedogenesis. Third, according to Birkland (1999), groundwater carbonates tend to be coarser grained and only fill in void space. However, the nodules at the Gault site are mainly micritic and many of the original silicate grains have been forced apart. Based on these characterizations, it appears that most calcium carbonate nodules at the Gault site are pedogenic and the remaining carbonates are lithogenic, or inherited from the original parent material.

Assessment of Calcium Carbonate Forms at the Gault Site

Based on field and micromorphological observation, the calcium carbonate nodules at the Gault site are both pedogenic and lithogenic. This study implies that carbonate nodules are predominantly pedogenic. In addition, the nature of accumulation and morphology of these nodules do not offer any clear evidence indicating that these nodules formed from groundwater processes.

First, by classifying stratigraphic units into stages of calcium carbonate accumulation, several patterns emerge. Calcium carbonate accumulation is very low in unit 3a. In units 3b and 4b, carbonate accumulation is higher compared to overlying unit 4c. In addition, carbonate accumulation is higher in units 5b and 6b compared to unit 7b. All of these sediments derived from the same drainage basin and inherited similar amounts of calcium carbonate. Therefore, the differences in carbonate accumulation between each unit is attributed to leaching of calcium carbonate which is facilitated by soil formation processes. Unit 3a was heavily leached before it was buried by unit 3b. Unit 4c underwent significant soil formation processes that resulted in the leaching of carbonates into units 3b and 4c. The lower concentrations of carbonate accumulation in units 5b and 6b may be the result of only moderate leaching due to their more recent deposition compared to underlying units or the moderate shift in climate and local moisture regime. Unit 7b has an even lower concentration of carbonate accumulation however this is the modern surface and once again, the requisite time necessary for leaching may not have occurred.

The morphology of the carbonate nodules at the Gault site is the second indicator that most nodules are pedogenic rather than lithogenic or groundwater carbonates. Lithogenic carbonates found in thin section include limestone and fossil fragments in addition to some nodules with sharp boundaries that appear to have been transported. Classification of pedogenic carbonate nodules in the sediments at the Gault site has been based on the guidelines set forth by West et al. (1988) and Birkland (1999).

Impact of Groundwater

Mobilization of Iron

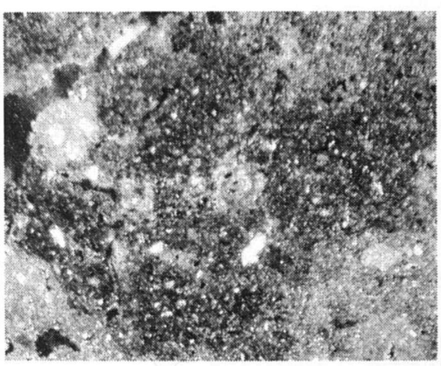
One way that the impact of groundwater can be interpreted is by considering the distribution and concentration of iron-staining of sediments. Redoximorphic (redox) features in seasonally saturated soils, traditionally referred to as mottles, signify the reduction, translocation, and oxidation of iron and manganese oxides (Vepraskas 1996). Analysis of redox features is crucial for understanding the movement of air and water through soils and sediments and can be used to evaluate water drainage. At the Gault site, redox features may suggest how these sediments have been affected by a fluctuating local water table over time. Accumulations of iron and manganese oxides (redox concentrations) occur under oxidizing conditions. Redox concentrations are found in the form of nodules, concretions, soft masses, and pore linings. They can occur on ped faces or in ped interiors. Under reducing conditions, iron and manganese have been removed from areas in the soil by mass movement by water or ion diffusion. These areas are known as redox depletions (chroma ≤ 2, value ≥ 4), and occur on ped faces or along pores (Vepraskas 1996).

Although redoximorphic features can change seasonally, it is possible for relict redoximorphic features to remain in a soil from a past period of soil development (Vepraskas 1996). The location of redox concentrations and depletions within a soil can assist interpretation of the oxidation state and movement of reductible iron and manganese species. This may also infer the direction of water movement. In general, ferrous iron moves from areas of low redox potential towards areas of high redox potential. For example, if redox depletions were located along macropores and redox concentrations were located in the soil matrix, then it can be assumed that reduction conditions are occurring at the pore interface and oxidation in the ped matrix. This may in turn infer that water was mostly moving from the macropores into the matrix. Conversely, if redox concentrations are found along macropores and redox depletions are located within the matrix, then ferrous iron must have been moving along a concentration gradient predominantly from the matrix to the macropores. Here iron and manganese are subsequently oxidized providing a continuing concentration gradient of a higher reduced species within the peds and more oxidized species at the ped surface (Vepraskas 1996).

Summary of Redoximorphic Features at the Gault Site

Redox features in thin section are readily visible in nearly every unit at the Gault site, corroborating field observations. Redox concentrations (e.g., nodules, concretions, and pore linings) are composed of oxidized iron (yellow-orange to red) and manganese (black) and occur both in the matrix and within calcium carbonate nodules (Figure 23). Fragments of limestone, chert, and chalcedony also appear to be iron-stained. Redox concentrations vary by abundance, contrast, morphology, composition, and concentration of staining between units. Redox features are summarized in Table 5.

a.



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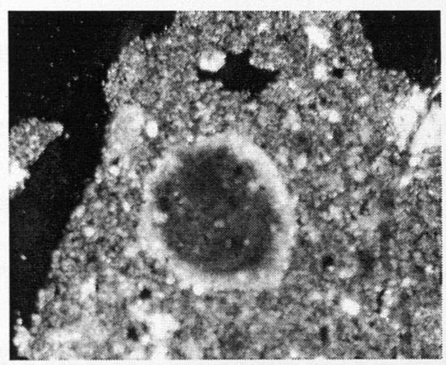

Figure 23. a. Matrix is stained by iron (darkening) in thin section 7E (Unit 3b). The field is 2.5 mm across and in cross-polarized light. b. Calcium carbonate nodule stained by iron to its outer edge in thin section 6488 (Unit 6b). The field is 1.0 mm across and in cross-polarized light.

Evidence for Groundwater Impact

Micromorphological evidence shows that unit 3a is capable of "perching" the water table in overlying units. The clays in this unit swell when saturated, sealing all

Table 5. Redoximorphic features.

Unit	Redoximorphic Features
7b	Few concentrations in carbonate nodules and a few stained pieces of chert.
6b	Decrease in redoximorphic concentrations. Calcium carbonate nodules are the most heavily stained compared to all other units.
5b	Iron staining of the matrix increases in unit 5b compared with unit 4c.
4c	Redoximorphic concentrations appear as light staining in the matrix of the lower part of the paleosol that increases towards the top of this unit. Staining becomes more distinct and darker at the top of the paleosol. Iron staining occurs in carbonate nodules, the matrix, and various fragments of limestone, chert, and chalcedony.
4b	Significant increase of redox concentrations compared to unit 3b. Frequent dark orange masses and the matrix has light orange staining. Many calcium carbonate nodules are stained in the center with an unstained outer cortex of calcium carbonate.
3b	Significantly fewer redox concentrations than unit 3a and they are much lighter orange. A few calcium carbonate nodules and infillings have some light staining.
3a	Patchy domains and soft masses that are dark orange to brown with distinctive boundaries

pore space and the unit becomes virtually impermeable. Therefore, a perched water table forms above this aquitard and the water table is blocked from filtrating to sediments below this unit. In addition, groundwater below unit 3a is blocked from rising and penetrating into overlying sediments. This phenomenon is know as *episaturation* and occurs in sediments within 2 meters of the surface (Vepraskas 1996). In the absence of unit 3a, the water table would be directly resting on the limestone bedrock. As a result of saturation caused by a perched water table, redox features and the development of pedogenic calcium carbonate forms in units overlying unit 3a may be in more advanced stages of formation compared with similar sediments not affected by episaturation.

Evidence for the shrink-swell of clays in unit 3a as the result of wetting and drying processes was clearly identified in field observation and in thin section. In the field, slickensides were found on all ped faces in unit 3a. In thin section, striated b-fabrics were observed only in unit 3a. Striated b-fabrics are formed by the reorganization of fabric when clay particles are oriented in the same direction in the matrix or around a particular feature which can be caused by wet-dry cycles in this unit (Bullock et al. 1985, Courty et al. 1989). In unit 3a, clay is oriented in the matrix (parallel and cross striated) and around voids (porostriated) and mineral grains, calcium carbonate nodules, and chert microdebitage (granostriated) (Figures 24, 25, 26, and 27). Due to episaturation above unit 3a, groundwater above this unit would have to flow laterally through the site. As a result, units above unit 3a periodically dry out due to the cycle of wetting and drying processes.

Assessment of Groundwater Impact at the Gault Site

Three components reflect the impact of groundwater at the Gault site: redox features, pedogenic calcium carbonates, and evidence of a perched water table over unit 3a. However, prominence and development of redox and calcium carbonate features are advanced because of the presence of a perched water table that elevated groundwater above levels typical of conditions without perched water conditions. Therefore, groundwater did have a significant post-depositional impact on sediments deposited at the Gault site which resulted in a much lower preservation potential for perishable materials such as paleoethnobotanical remains.

This issue also raised questions about the main direction of water flow through this section of the site. Water flow appears to have been restricted by the perching of

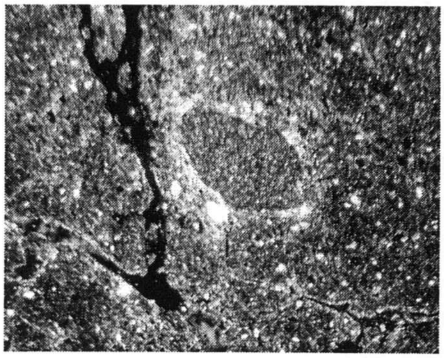

Figure 24. Oriented clay (whitish material) around rounded chert grain. Field is 1.0 mm across and in cross-polarized light. Thin section 9a (Unit 3a).

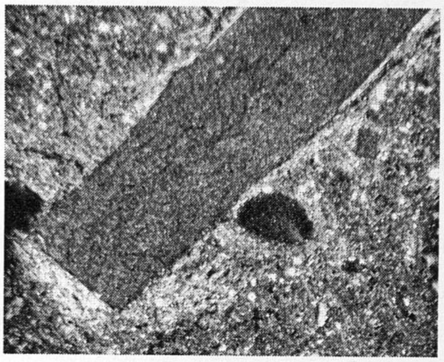

Figure 25. Oriented clay (whitish material) around angular chert grain. Field is 2.5 mm across and in cross-polarized light. Thin section 9a (Unit 3a).

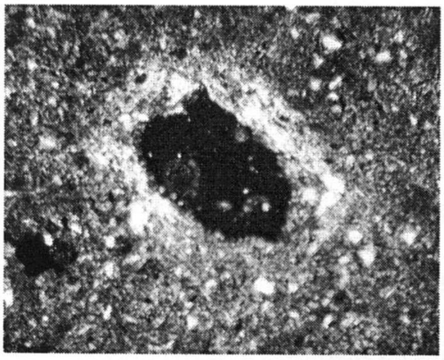

Figure 26. Oriented clay (whitish material) around void. Field is 1.0 mm across and in cross-polarized light. Thin section 9b (Unit 3a).

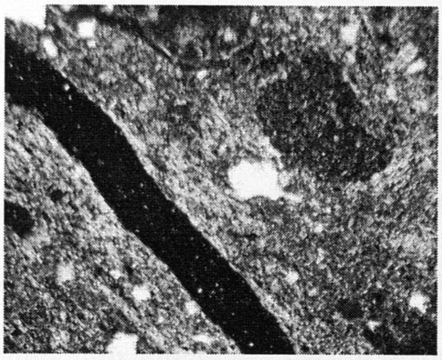

Figure 27. Oriented clay (whitish material) along channel void. Field is 1.0 mm across and in cross-polarized light. Thin section 13.2 (Unit 3a).

unit 3a, which caused water to flow laterally across the site during periods of high discharge. During periods of low discharge, based on the presence of strong mottling in unit 4c (a paleosol) and below, water mainly seeped upwards into these units from seasonally saturated conditions above the aquitard. In addition, because redox features are less prominent in units overlying unit 4c (i.e., units 5b, 6b, and 7b), these units may have been saturated less frequently. Therefore, its main impact was on these lower sediments containing the oldest archaeological material at the site.

Additional Post-depositional Processes: Biological Activity (Micro-bioturbation)

Analysis of bioturbation, the alteration of soils and sediments by organisms, emerged in the study of sediments and soils at archaeological sites in the 1970s (Butzer 1982, Schiffer 1987, Wood and Johnson 1978). Bioturbation is subdivided into floralturbation (disturbance by plants) and faunalturbation (disturbance by animals and insects) (Buol et al. 1997). Today, attention is given to the activities of burrowing animals, earthworms, termites, and plant roots and how they affect archaeological sites. Movement of artifacts and datable materials, such as charcoal, within a site is of great concern because artifacts can move vertically by falling into animal burrows or being transported into older or younger deposits by subterrestrial animal activity (Butzer 1982). Such disturbance could lead to erroneous data and archaeological interpretations. However, bioturbation on the small-scale can also significantly impact a site. Micromorphological analysis has proven to be a powerful tool in the investigation of bioturbation and its impact at archaeological sites particularly in the small-scale micro-bioturbation of small organisms (e.g., ants and earthworms). Micro-bioturbation can have a large-scale impact but is hardly discernable in the field. At the Gault site, it was important to determine whether there were occupation surfaces visible in thin section that were not observed in the field and whether organic material was present and had deteriorated *in situ* because it was rarely observed during excavation.

Micro-bioturbation at the Gault Site

Evidence for micro-bioturbation is common in all stratigraphic units at the Gault site. It is not surprising that organisms were active at this site, as sediments were never frozen and the dense vegetation of the modern environment implies that the area has been fertile for some time. Thin section analysis revealed two types of evidence for bioturbation: 1) plant material (e.g., roots), and 2) evidence of small animal activity, (e.g., insects and earthworms). Modern roots are found in nearly all units including unit 3a, the deepest unit containing artifacts. Small burrows are also found in most stratigraphic units and may have been made by earthworms, ants, or other small organisms common to Central Texas. In thin section, burrows are different from typical planes and voids that form naturally in sediments and soils because they are often irregularly shaped, disconnected, and many times filled with material that appears to be different from the matrix of the sediment. These channels are called infillings and often include fecal material or fecal pellets (Figure 28). In some units, roots were broken up into small pieces and scattered throughout the matrix (Figure 29). In other cases, roots

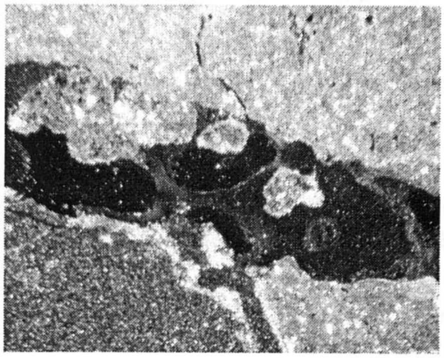

Figure 28. Burrowing channel with infilling of fecal material. Field is 2.5 mm across and in cross-polarized light. Thin section 5c (Unit 4c).

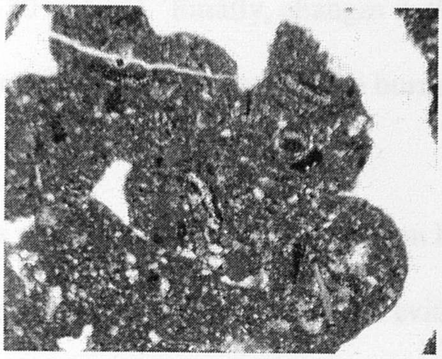

Figure 29. Root material that has been broken up by bioturbation. Field is 2.5 mm across and in plane-polarized light. Thin section 6491 (Unit 5b).

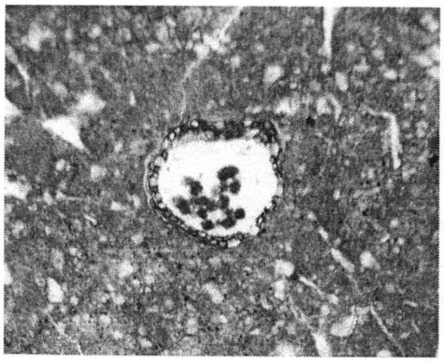

Figure 30. Internal root material has been digested and fecal pellets lie inside the remains of the root structure. Field is 1.0 mm across and in plane-polarized light. Thin section 4a (Unit 5b).

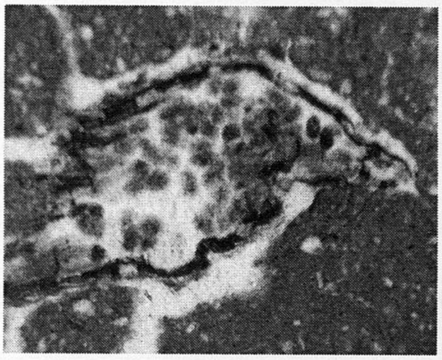

Figure 31. Internal root material has been digested and fecal pellets lie inside the remains of the root structure. Field is 1.0 mm across and in plane-polarized light. Thin section 7a (Unit 4c).

were not simply broken into pieces, but the internal root matter was digested by animals and deposited in the form of fecal pellets (Figures 30 and 31). Finally, changes in the density or porosity of the matrix provides evidence of bioturbation even when burrows are not clearly defined.

Through micromorphological analysis, it is evident that micro-bioturbation has had a significant impact on the preservation of organic matter and any potential evidence for occupation surfaces at the Gault site. During fieldwork, reasons for the lack of macro organic material was unclear. In thin section, organic matter is present in nearly every sample, although as fine particles (silt-size and smaller) dispersed throughout the matrix that are difficult to see with the unaided eye (Figures 32 and 33). This explains why they were not detected in the field. Pieces of charcoal are present, but they were also found as small fragments and scattered throughout samples (Figures 34 and 35). The fragmentation of these materials strongly suggests that they have been significantly micro-bioturbated. Earthworms are particularly attracted to charcoal and are able to churn up units through ingestion and excretion (Goldberg 1998). The nature of organic matter and charcoal found in these units combined with the evidence for bioturbation strongly suggests that organic matter was broken up *in situ* by organisms. Furthermore, it is likely that occupation surfaces were disturbed in this manner, making it nearly impossible to discern them in the field or thin section.

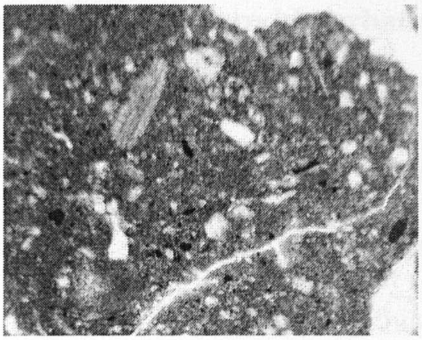

Figure 32. Fine organic matter (black fragments) scattered throughout the matrix. Field is 1.0 mm across and in plane-polarized light. Thin section 4a (Unit 5b).

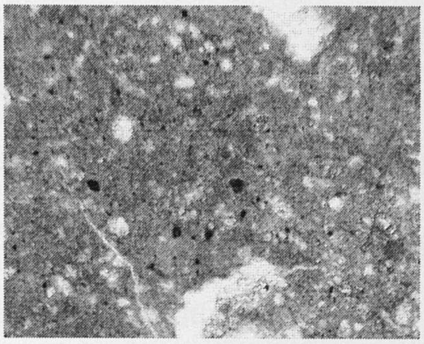

Figure 33. Fine organic matter (black fragments) scattered throughout the matrix. Field is 1.0 mm across and in plane-polarized light. Thin section 6a (Unit 5b).

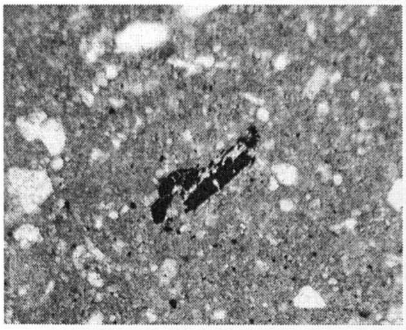

Figure 34. Fragment of charcoal or burnt wood. Field is 1.0 mm across and in plane-polarized light. Thin section 6490 (Unit 5b).

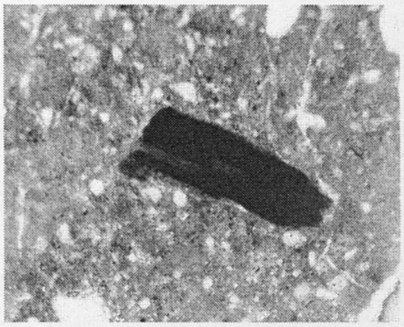

Figure 35. Fragment of burnt wood. Field is 1.0 mm across and in plane-polarized light. Thin section 6c (Unit 4c).

Assessment of Micro-bioturbation at the Gault Site

Micro-bioturbation at the Gault site has been shown to have had an impact on all of the stratigraphic units that contain archaeological material. Therefore, a qualitative understanding of the effect of micro-bioturbation is crucial for evaluating site integrity and the disturbance caused by this post-depositional process. Although micro-bioturbation is small-scale relative to movement of artifacts by larger burrowing animals or unsystematic excavation, it is still important to understand its effect on the stratigraphy and decomposition of ecofacts. Analysis of micro-bioturbation at the Gault site has shed some light on why distinct occupation surfaces have not been found in the field or under the microscope, why the boundaries of stratigraphic units are difficult to define, and why evidence of charcoal and organic matter has been found only in small fragments dispersed throughout the matrix.

Archaeological Evidence in Thin Section

Microdebitage, Charcoal, Bone, and *Rabdotus* Shell Fragments

On the microscale, archaeological evidence at the Gault site was limited to chert microdebitage (Figures 36, 37, and 38), bone (Figure 39), and charcoal fragments as discussed previously. Chert microdebitage found in thin section correlated fairly well with excavation records of artifacts. However, the presence of microdebitage in thin section is not always a strong guideline to follow because it tends to occur by chance in thin section (Paul Goldberg, personal communication). Bone fragments were not common in thin section. Fragments of charcoal found within the stratigraphic units

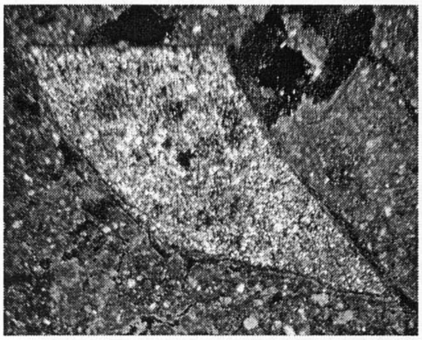

Figure 36. Angular fragment of archaeological chert microdebitage. Field is 2.5 mm across and in cross-polarized light. Thin section 3c (Unit 6b).

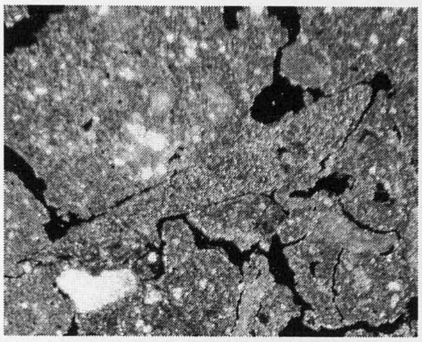

Figure 37. Long angular fragment of archaeological chert microdebitage. Field is 2.5 mm across and in cross-polarized light. Thin section 6490 (Unit 5b).

Figure 38. Triangular fragment of archaeological chert microdebitage. Field is 2.5 mm across and in cross-polarized light. Thin section 6a (Unit 5b).

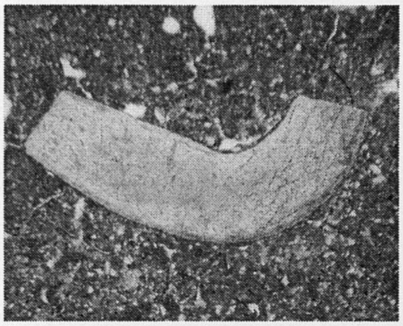

Figure 39. Bone fragment. Field is 2.5 mm across and in plane-polarized light. Thin section 7a (Unit 4c).

suggest the use of fire by prehistoric humans at the site. These fragments were usually small and scattered throughout the matrix. However, two charcoal samples from the Clovis pond clays of Unit 3a produced dates of 150 ± 50 yr. BP (CAMS-65536) and 230 ± 40 yr. BP (CAMS-65542). This suggests that at least some of the charcoal if not all of the charcoal observed in thin section is the byproduct of modern burning (e.g., burnt roots) that were dispersed in the late Quaternary sediments by bioturbation. As mentioned before, distinct occupation surfaces that correlate with this archaeological material were not found in thin section. It is likely that these surfaces were disturbed by micro-bioturbation and are not visible in thin section.

Rabdotus Shell Fragments in Unit 5b and Unit 6b

The last indicator for post-depositional alteration considered through micromorphological analysis was restricted to units 5b and 6b, two units overlying the paleosol (unit 4c). Both units, particularly unit 6b, contain a significant amount of *Rabdotus* shell fragments. At this time, it is not clear how shells became incorporated into these sediments. Some studies suggest that *Rabdotus* shells were used as a prehistoric food source (Brown 2002). On the other hand, it is possible that these snail shells were deposited at the site with other colluvial clasts. Analysis of these shells in thin section did not provide conclusive evidence for either explanation. Regardless, *Rabdotus* shells are very abundant in units 5b and 6b and rarely found in unit 4c and below.

In thin section, these shells are found broken into pieces and fully preserved

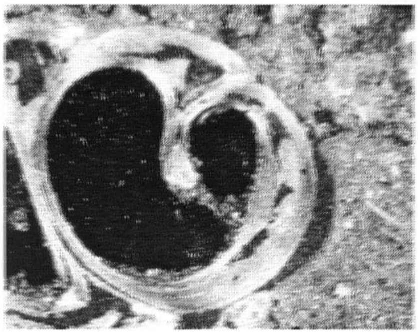

Figure 40. Articulated *Rabdotus* shell. Field is 2.5 mm across and in cross-polarized light. Thin section 3b (Unit 6b).

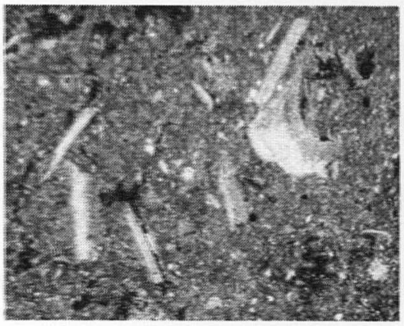

Figure 41. Broken *Rabdotus* shell fragments. Field is 2.5 mm across and in cross-polarized light. Thin section 3c (Unit 6b).

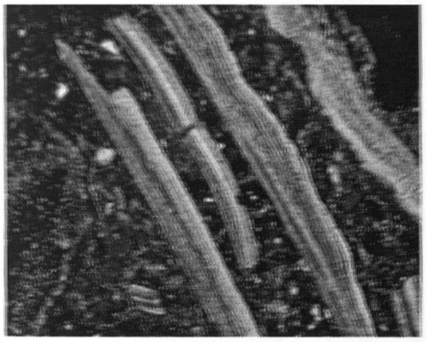

Figure 42. Broken *Rabdotus* shell fragments lying parallel. Field is 2.5 mm across and in cross-polarized light. Thin section 3a (Unit 6b).

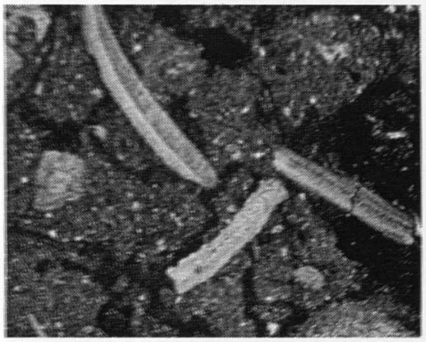

Figure 43. Broken *Rabdotus* shell fragments lying at various angles. Field is 2.5 mm across and in cross-polarized light. Thin section 3a (Unit 6b).

(Figures 40 and 41). Some shells lie parallel to each other while others lie at various angles to one another (Figures 42 and 43). A number of the shells were broken in place, (Figure 44), and others appear to be dissolving *in situ* (Figure 45). Although it is not conclusively understood why these shells are present in these units, it is clear that they have been disturbed by post-depositional processes, such as animal burrowing and root growth. It is also possible that some shells were broken as a result of trampling and some could have broken during thin section processing. However, no evidence of trampling, such as bedding or compaction, has survived.

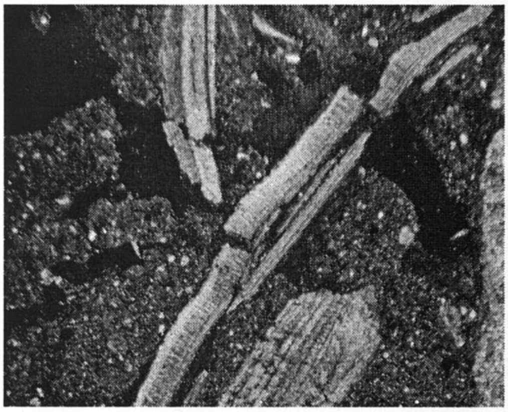

Figure 44. *Rabdotus* shell fragments broken *in situ*. Field is 2.5 mm across and in cross-polarized light. Thin section 3a (Unit 6b).

Figure 45. *Rabdotus* shell fragment weathering *in situ* from the inside. Field is 2.5 mm across and in cross-polarized light. Thin section 3b (Unit 6b).

Paleoenvironmental Models for Texas and the Gault Site

The final stage in the analysis of the micromorphology of the Gault site sediments is to attempt to place these sediments into their paleoenvironmental context.

In turn, it will be possible to understand more clearly the depositional and post-depositional history of this site and the conditions under which sediments were deposited, eroded, and pedogenically altered. This requires a brief review of current paleoenvironmental models that have been constructed based on studies at sites throughout Texas. This is a necessary comparison for this study because pollen evidence was not recovered at the Gault site and faunal analysis, stable carbon isotope analysis, and geomorphological studies are still in progress. Nonetheless, after consideration of these models it will be possible to place micromorphological data from the Gault site into this regional paleoenvironmental framework and consider how the Gault data relates to other models.

Current Paleoenvironmental Models for Texas

Evidence for the paleoenvironmental reconstruction of Central Texas comes from a variety of sources: 1) fossil pollen from peat bogs (Bryant and Holloway 1985, Bousmann 1998), 2) faunal remains from datable stratigraphy (Toomey 1993, Toomey et al. 1993), 3) geomorphological changes (Haynes 1991, 1993), and 4) stable carbon isotope analysis (Ferring 2001, Nordt et al. 1994). The value of these independent investigations of the paleoclimate is that these reconstructions correlate with and reinforce each other. It is important to emphasize that all of the final interpretations of this evidence, whether it is pollen, bone, stratigraphic exposures, or pedogenic carbonates, are based on qualitative assumptions or data. As a result, each paleoclimatic model varies slightly from one another. However, because the focus spans 12,000 years, it is more practical to concentrate on the broader paleoclimatic trends.

From the Late Pleistocene until the Early Holocene, pollen, faunal, and geomorphic studies imply a xeric climatic trend (decrease in precipitation and increase in temperature) with scouring, valley downcutting, and soil formation. This phase was followed by a return to wetter and cooler mesic conditions with valley filling until the early Middle Holocene (c. 9000-8000 BP). The Middle Holocene Altithermal was a longer phase of drier and warmer xeric conditions that lasted approximately 5000 years (c. 9000/8000 until 5000/4000 BP). The Late Holocene (c. 5000-4000 BP) returned to mesic conditions that have continued relatively unchanged until the present.

According to the stable carbon isotope evidence (Ferring 2001, Nordt et al. 1994), there are only two minor variations from the model mentioned above. One occurred during the Late Pleistocene until ca. 11,000 BP. This period was cooler with increased precipitation (45-50% of the biomass consisted of C_4 plants) compared to the drier conditions of the model from the pollen, faunal, and geomorphic evidence. The second variation occurred from ca. 11,000-8000 BP. This period was warmer and more arid (a slight increase of C_4 plants to 65-70% of the biomass population) in contrast to the more mesic phase of the previous model. At the Middle Holocene, all models imply a warmer and drier Altithermal period of prairie expansion (increase of C_4 plants to 85-95%), valley erosion, and soil formation.

Paleoclimatic evidence from Central Texas corresponds well with the paleoenvironmental models formulated as a result of work conducted at the Aubrey Site in Northern Texas (Ferring 2001). Geochemical, botanical, and faunal analyses appear to indicate that the end of the Pleistocene was cool and dry. Pollen evidence shows that uplands had grasses and the floodplains contained trees and shrubs. Cool grassland existed at least until the beginning of the Clovis period. Investigations of fossilized insects implied a gradual warming trend from 14,000 until 13,300 BP. Geomorphic studies show that from 15,000-11,000 BP the climate was stable and the Early Holocene became a moister climate with moderate to rapid alluviation. The Middle Holocene returned to a period of stability that allowed pedogenesis and a drier climate. Alluviation was more intense during the Late Holocene as the climate became moister. Data from carbon isotope analysis indicate a more humid Early and Late Holocene and a drier Middle Holocene. Oxygen isotope analysis indicates that the Middle Holocene annual temperature was similar to modern conditions.

At the Gault site, current data for paleoenvironmental reconstruction is limited. Sampling for pollen at the site yielded no results, as pollen was likely destroyed by fluctuating wet-dry cycles. Analysis of faunal remains, stable C isotopes, and geomorphology are still in progress and will be reported at a later date. However, there are some indications that may reflect paleoenvironmental changes through micromorphological analysis. First, there is significant evidence for changes in sedimentation rates as discussed in Chapter II. In addition, two other types of data suggest variations in climate trends during the history of this site: deposition of eolian quartz and changes in the nature of redox concentrations within calcium carbonate nodules through time.

Change in Mean Sedimentation Rate

As discussed in Chapter II, a significant drop in the sedimentation rate or yield after 8500 BP could imply that during the past 8500 years, deposition at the Gault site: 1) was incremental and slow, with little soil development, or 2) consisted of larger depositional events followed with longer periods of stability and sustained pedogenesis. A similar change in hydrologic regime around 8500 years BP was noted by Waters and Nordt (1995) in the Brazos River valley in East-Central Texas where a shift from lateral accretion deposits to predominantly vertically accretion deposits occurred as a result.

At the Gault site, the evidence in thin section supports an incremental and slow deposition of the units overlying the paleosol. Units 5b, 6b, and 7b have weaker characteristics of soil development (e.g., redox features and calcium carbonate accumulation) compared to underlying units. During the formation of units 5b, 6b, and 7b, the lack of extensive of soil development could be attributed to a drier climate suggested by paleoenvironmental models. However, there is another element of these units that is more supportive of more discrete depositional events: colluvium. In the units above the paleosol, the amount of large angular clasts increases significantly in comparison to underlying units. These clasts are also evenly scattered throughout each unit, which could correspond to small-scale slumping events during the course of slow and incremental alluvial deposition. The presence and distribution of colluvial clasts coupled with the lack of soil development could suggest that units overlying the paleosol (unit 4c) were slowly deposited over a long period of time (8500 years) during a period of limited precipitation. This type of slow deposition would also impede the rate of soil development, as is evident in units 5b, 6b, and 7b. However, this issue can not be completely resolved without definitive radiocarbon dates from these units.

Eolian Quartz Dust

Another factor in the reconstruction of the paleoenvironment at the Gault site may be the presence of eolian quartz dust. Sediments at the Gault site are predominantly alluvial in origin mixed with some colluvium eroding from upslope. However, another source of sediment was discovered in thin section: eolian dust. Silt-sized quartz dust (0.0625 - 0.002 mm) was observed in every stratigraphic unit at the Gault site. This is unusual because quartz is not part of the local limestone bedrock that produced these alluvial and colluvial sediments (Huckabee 1977) (Figure 46).

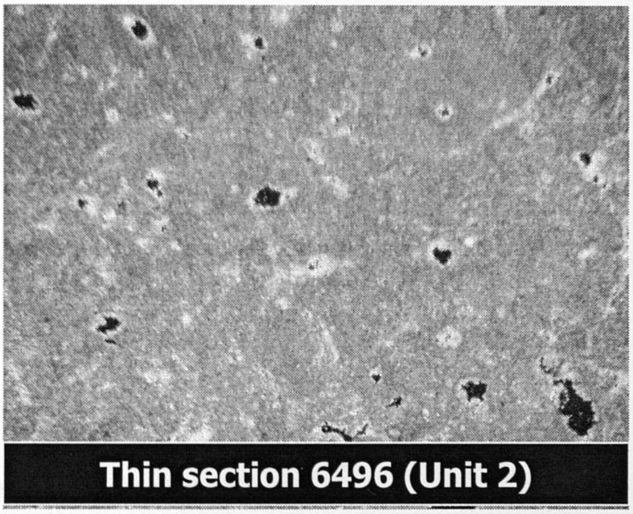

Figure 46. Matrix of unit 2 which is composed of decomposed Edwards limestone without any quartz grains. The field of view is 2.5 mm across and this thin section is viewed in cross-polarized light.

In addition, there is no known local source of quartz; therefore, it must be eolian in origin although it could have been deposited within alluvial and colluvial sediments that have been eroded to form the sediments deposited at the Gault site. This corroborates with other studies of eolian quartz dust in Central Texas (Drees et al. 1985, Rabenhorst et al. 1984, and West 1986). In thin section, density of eolian quartz dust varied considerably between units, which may also help define climate changes.

Central Texas Dust Collection

The presence of quartz dust in soils has also been noted in several previous studies of Central Texas (Drees et al. 1985, Goldberg 1998, Nordt 1996, Rabenhorst et al. 1984, West 1986). In the 1980s, soil scientists investigated the composition of dust in soils of various regions in Texas (Drees et al. 1985, Rabenhorst et al. 1984, Rabenhorst and Wilding 1986c, West 1986). In the first study, seven dust collecting traps were placed over a 100,000 km^2 area of Central and Western Texas (Rabenhorst et al. 1984). Dust composition, mineralogy, and rate of deposition were determined. Dust collected from these traps consisted of approximately 85% eolian clay and silt. Clay composition was dominated by mica and quartz with small amounts of smectite and kaolinite. The silt fraction was mainly composed of quartz with some alkali feldspars. As a result of this analysis, it was determined that the dust was not locally derived so the primary source of this dust was located outside the region. In addition, the study concluded that the dust was deposited regionally based on common features between dust collected in different areas and that the rate of deposition was 1 mm/100 years.

The findings of the Rabenhorst et al. (1984) study were supported by a similar project conducted by West (1986). In this study, four dust traps were placed throughout Central Texas over a 3-year period. Dust composition was found to be comparable with the previous study with 90 % eolian clay and silt. The composition of clay was dominantly quartz in addition to small amounts of mica, kaolinite, and expandable 2:1 layer silicates. The silt was composed of quartz and some feldspar. In addition, the deposition rate based on this study was calculated as 1-2 mm/100 years.

Summary of Quartz Dust of the Gault Site

At the Gault site, quartz grains are present in the sediment of every stratigraphic unit that was sampled at the Gault site and was also found in some calcium carbonate nodules (Figure 47). Frequency of quartz grains ranges from few (5-15%) to frequent (15-30%) and size distribution varies from mainly coarse to very fine silt grains. In addition, when quartz was more abundant, it tended to be composed of coarser grains. In unit 3a, the matrix contains around 15% quartz grains ranging from coarse to very fine silt, although a majority is coarse silt. Unit 3b also contains around 15% quartz grains but in comparison to unit 3a, quartz grains are slightly finer. In units 4b and 4c, quartz appears more sparse in thin section (around 10%) and most grains are uniformly fine silt. Quartz slightly decreases in unit 4c (around 5-10%), where there is only a moderate amount of fine quartz, although it increases towards the top of unit 4c (paleosol) to around 10%. Units 5b and 6b also have around 10% amounts of quartz silt

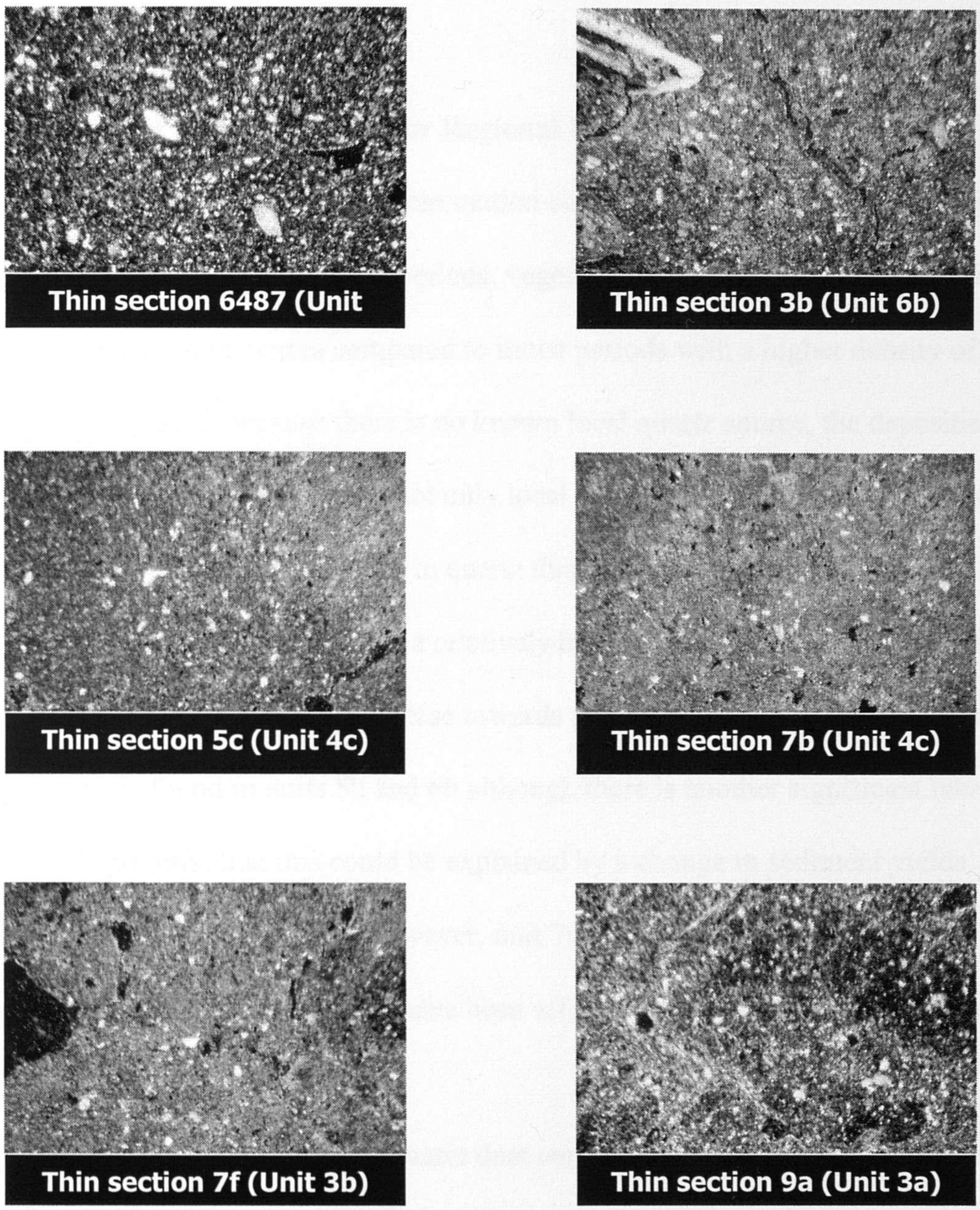

Figure 47. Matrix of all units with quartz silt (white grains). The field of view is 2.5 mm across and in cross-polarized light for all photographs.

similar to the top of unit 4c. Unit 7b shows an increase in frequency of quartz (around 15%) and coarseness of the grains which are dominantly coarse silt.

Quartz Dust and Its Implications for Regional Climate Change

The amount of eolian dust in circulation could be linked to relative climate changes. For example, during drier periods, vegetation cover will decrease and wind erosion of sediments increases compared to moist periods with a higher density of vegetation. However, because there is no known local quartz source, the deposition of quartz dust at the Gault site reflects not only local climate trends, but regional trends. The basic pattern formed by changes in quartz dust concentrations within the stratigraphic units at the Gault site is a relatively high concentration in units 3a and 3b, and a decrease in unit 4b and an increase towards the top of 4c. Only moderate amounts of quartz dust is found in units 5b and 6b although there is another significant increase in unit 7b. It is possible that this could be explained by a change in sediment yields following the deposit of unit 4c. However, unit 7b has a relatively high concentration of quartz dust and this unit would also have been affected by the shift in sediment yields following the deposition of unit 4b.

Nonetheless, this pattern of quartz dust concentrations could imply that the climate was comparatively drier during the deposition of units 3a and 3b, wetter during the deposition of units 4b and 4c, drier during the formation of the paleosol on unit 4c, and drier during the deposition of units 5b, 6b, and 7b. When compared to the current paleoenvironmental models for Central Texas, the model proposed by eolian quartz deposition at the Gault site correlates fairly well although it most closely resembles the model established by the stable carbon isotope data (Nordt et al. 1994).

Redox Concentrations Within Calcium Carbonate Nodules Above and Below Unit 4c (the Paleosol)

The final form of micromorphological evidence that may reflect climate changes is the iron-staining of calcium carbonates above and below the paleosol (unit 4c). Two distinctive patterns of iron-staining of calcium carbonate nodules emerged from thin section analysis comparing units below and above the paleosol. Iron-stained calcium carbonates in the units below the paleosol are commonly stained in the core of the carbonate nodule (core-stained), leaving an unstained outer cortex of calcium carbonate (Figure 48). Nodules stained in units above the paleosol are generally uniformly stained

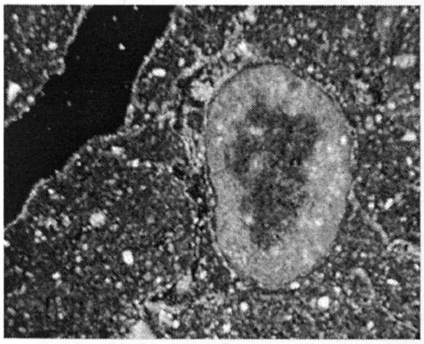

Figure 48. Calcium carbonate nodule stained by iron in central core. Field is 2.5 mm across and in cross-polarized light. Thin section 6a (Unit 4c).

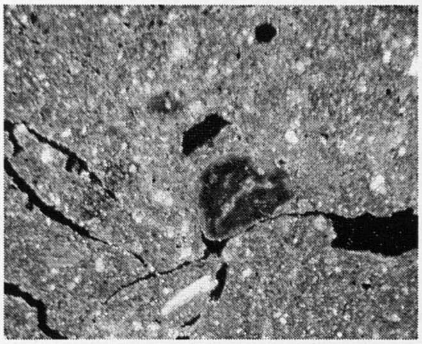

Figure 49. Calcium carbonate nodule stained by iron to its outer edge. Field is 2.5 mm across and in cross-polarized light. Thin section 6491 (Unit 5b).

to the perimeter of the nodule (fully-stained) (Figure 49) or are unstained. This analysis suggests that staining of carbonate nodules may reflect fluctuations in local moisture conditions (including seasonal changes) or in the regional climate.

The formation of core-stained nodules would occur in several stages. First, following a drier period, calcium carbonate goes into solution during a wetter period and then precipitates into a unit and forms filaments and nodules *in situ* during another drier period. Next, iron mobilized during a wetter period enters the system and stains nodules as it also precipitates during a dry period resulting in a fairly homogenous staining of carbonate nodules. This is how the fully-stained nodules found in the upper sediment may have formed. Followed by another wet-dry sequence, additional calcium carbonate could precipitate into the unit and coat the fully-stained nodules with another layer of carbonate. As a result, the fully-stained nodule would evolve into core-stained nodules as were found mostly in units below the paleosol. This series of events is significant because a majority of carbonates in the lower units (units 3b, 4b, and 4c) are stained in the core. Stained carbonates found in the upper units are typically stained throughout the nodule to the perimeter.

As in the case of precipitation of calcium carbonate previously discussed, there must have been some change in the environment to trigger changes that resulted in the precipitation of calcium carbonate and iron. Detailed descriptions of climate influences on the dissolution of calcium carbonate and mobilization of iron can be found in Anderson (1984), Arkley (1963), Birkland (1999), Bouma (1983), Brook et al. (1983), Collins and Buol (1981), Rowell (1981), Schlesinger (1985), and Wilding et al. (1983).

In summary, calcium carbonate and iron will move within a system when pH decreases and saturation increases. Therefore, during wetter periods there is an increased precipitation of calcium carbonates and production of filaments and nodules as well as a mobilization of iron in the system. During drier periods, calcium carbonate will precipitate out of solution forming filaments and nodules, and iron will also precipitate staining pore linings, the matrix, or carbonate nodules.

Site Formation Processes and Paleoenvironmental Change at the Gault Site

This study has proposed several types of evidence that may help clarify the history of site formation and paleoenvironmental change at the Gault site. Table 6 summarizes site formation processes at the Gault site based on micromorphological evidence and field observation.

Prior to the deposition of Units 1 and 2, an erosional event towards the end of the Late Pleistocene scoured the bedrock surface of weathered limestone. Following this event, Unit 1 (colluvial limestone gravels) was deposited followed by the deposition of Unit 2 (alluvial chert gravels) on the bedrock surface.

The Clovis clay (Unit 3a) was deposited over gravel Units 1 and 2 and accumulated in a narrow pond behind the bar comprised of Unit 1 gravel. The clay contains Clovis artifacts *in situ* in addition to chert microdebitage, ash rhombs, and ca. 15% coarse to very fine quartz silt. Unit 3a is characterized by a high percentage of clay (60%) and low percentage of calcium carbonate (3%). The drainage area around the Gault site contains highly calcareous sediments and this is the source for alluvial

Table 6. Formation processes at the Gault site.

Stratigraphic Unit	Cultural Period and Artifacts	Depositional Processes: Geogenic	Depositional Processes: Anthropogenic	Post/Syn-Depositional Processes
7b	Archaic -Present	Low-energy floodplain deposition of silty clay sediment with silt-size quartz grains	Chert flakes Microdebitage	Modern roots
6b	Archaic	Low-energy floodplain deposition of clay (50%) with numerous *Rabdotus* shell fragments and gravel-size clasts	Chert flakes Possible tooth	Iron concentration and depletion Precipitation of carbonate by nodules and hypocoatings Calcium carbonate nodules iron-stained to nodule edge Bioturbation
5b	Archaic	Low-energy floodplain deposition of silty clay (50%) sediment with silt-size quartz grains (40%)	Ash Charcoal Wood Chert flakes Possible eggshell Microdebitage	Moderate iron concentration and depletion lighter than underlying units. Moderate precipitation of calcium carbonate (45%) Calcium carbonate nodules iron-stained in nodule edge Bioturbation by broken up plant material, spongy fabric, and fecal pellets
8,500 BP Climate Change: erosional event and truncation of paleosol				
4c	Folsom - Angostura (points)	Low-energy floodplain deposition of clayey (50%) sediment with quartz silt (40%) and gravel-size clasts	Chert flakes Ash rhombs Burnt wood	Iron concentration and depletion Perpendicular planar voids (soil structure) Precipitation of carbonate (drop from unit 4b) Bioturbation: broken up roots, organic matter, and fecal pellets.
		Possible erosional event		
4b		Low-energy floodplain deposition of clayey sediment (50%) containing quartz silt (40%) and few colluvial clasts of quartz, calcite, chalcedony, and limestone.	Chert microdebitage and bone fragment only at top of unit	Scattered organic matter due to bioturbation Significant iron concentration and depletion that decreases with elevation Significant precipitation of carbonate (nodules and hypocoatings) that decrease with elevation Calcium carbonate nodules iron-stained in core only
	Erosional event			
3b	Clovis (points, cores, blades, overshot flakes)	Low-energy floodplain deposition of clay (40-50%) with quartz silt (15-20%)	Chert microdebitage Bone	Bioturbation Significant precipitation of iron Significant precipitation of calcium carbonate (nodules and hypocoatings) Calcium carbonate nodules iron-stained in core only
	Colluvial deposition slightly upslope from main column.			
3a	Clovis (points, cores, blades, overshot flakes)	Deposition of pond clay sediments containing clay (60%) and Unit 3a acts as an impermeable layer creating a perched water table in overlying units.	Chert microdebitage Ash rhombs One sandstone clast	Moderate iron concentration and depletion Striated b-fabric (due to shrink-swell of sediment) Little calcium carbonate precipitation (only 3% CaCO3)
1 and 2		Deposition of colluvial limestone gravels (Unit 1) Deposition of alluvial chert gravels (Unit 2)		
	Erosional event that scoured limestone surface.			
Bedrock		Weathered limestone that may have been reworked in place.		

sediments deposited at the site. Therefore, the low percentage of calcium carbonate found in Unit 3a suggests that this unit underwent a period of extensive leaching of calcium carbonate because it originally contained a high percentage of calcium carbonate when it was deposited. Moderate iron concentrations and depletions were also observed in thin section. Therefore, extensive leaching and the presence of redoximorphic features suggest that this unit underwent soil formation and groundwater frequently rose to this unit. In addition, striated b-fabrics observed in thin sections of Unit 3a strongly suggest high shrink-swell potential for this unit, causing periodic episaturation in overlying units. Last, a small colluvial wedge overlying Unit 3a was observed slightly upslope from the main column where samples were collected. This suggests that there was a period of stability following the deposition of Unit 3a allowing for soil formation.

Unit 3b (the Clovis Soil) is a low-energy floodplain sediment that was deposited over Unit 3a. This unit also contained *in situ* Clovis artifacts in addition to chert microdebitage, bone fragments, and ca. 15% quartz silt that is slightly finer than quartz found in Unit 3a. Bioturbation, redoximorphic concentrations, and pedogenic calcium carbonate nodules were also observed. The concentration of redoximorphic concentrations and accumulation of calcium carbonate significantly increases in this unit compared to Unit 3a. This suggests that soil formation in Unit 3b was more developed than Unit 3a. However, the water table may not have risen as frequently in this unit compared to Unit 3a because carbonate leaching was not as extensive. In any case, when groundwater did rise into Unit 3b, it was likely perched above Unit 3a.

Units 4b and 4c were deposited as low-energy floodplain sediments during the late Paleoindian period (Folsom through Angostura, ca. 11,000-8800 BP). These units are separated by a small erosional event observed in the field which is further substantiated by micromorphological evidence that shows a significant change in carbonate nodule concentration between Units 4b and 4c. In thin section, Unit 4b contains chert microdebitage, bone fragments, scattered organic matter, significant redoximorphic features, significant carbonate accumulation, and ca. 10% fine quartz silt. Unit 4c contains chert flakes, ash rhombs, burnt wood, moderate redoximorphic features, soil structure, moderate carbonate precipitation, and ca 5-10% fine quartz silt. The development of soil structure in Unit 4c and the increase of iron-staining and calcium carbonate accumulation in Unit 4b suggests significant soil formation of Units 4b and 4c. In addition, it is likely that groundwater did not rise above Unit 4b very often because a majority of the iron-staining occurs in Unit 4b. Although it is possible that there was a small erosional event separating these Units 4b and 4c, it is also possible that they are distinguished through soil horizonation, whereas Unit 4b is the remains of a Bk1 horizon and Unit 4c was the underlying Bk2 horizon. Furthermore, based on field observation, Unit 4c was truncated by an erosional event that may have corresponded to the climate change that occurred ca. 8500 BP (Middle Holocene Altithermal) according to the paleoenvironmental record of Central Texas as discussed previously. Units 4b and 4c may correlate with the Royalty Paleosol identified at Fort Hood (Nordt 1993, 1996) where charcoal in this paleosol dated to 8830±70 (Beta 63007).

Following this event was the deposition of Unit 5b, a low-energy floodplain silty-clay deposit. This unit contains Archaic artifacts and thin sections revealed ash, charcoal, wood, chert flakes and microdebitage, a possible eggshell piece, and ca. 10% fine quartz silt. Moderate redoximorphic concentrations and carbonate precipitation were also observed in this unit. Next, Unit 6b (Shell Hash Midden) was deposited over Unit 5b. Unit 6b also contains Archaic artifacts in addition to numerous *Rabdotus* shell fragments, chert flakes, a possible tooth fragment, and ca. 10% fine quartz silt. Redoximorphic concentrations and carbonate precipitation are slightly less prominent than Unit 5b. Nonetheless, based on observation in the field and in thin section, there is evidence of moderate soil formation in Unit 6b. Unit 7b was deposited over Unit 6b. Unit 7b is a low-energy silty-clay floodplain deposit containing Archaic through modern artifacts in addition to chert flakes, microdebitage, modern roots, and ca. 15% coarse quartz silt. Based on the reduced concentration of iron-staining in these upper units, it is clear that these units are better drained than Units 3a, 3b, 4b, and 4c, and that the water table rarely rose into these upper units.

After evaluating all lines of evidence that resulted from this study, it is apparent that certain evidence is more substantial and supportive of current paleoenvironmental models for Central Texas than others. Evidence under consideration for reflecting climatic trends included: 1) precipitation of secondary calcium carbonate and mobilization of iron, 2) changes in mean sedimentation rate and yield, 3) density of quartz dust, and 4) characterization of iron-staining of calcium carbonate nodules.

The precipitation of carbonate and distribution of redoximorphic concentrations are the clearest indicators of paleoenvironmental change as they are traced through each stratigraphic unit. The three other lines of evidence have interesting potential and may be clarified by further study. However, at this time they should be considered potential indicators for climatic change for several reasons. First, analysis of the shift in mean sedimentation rate and yield indicated that there was a hydrologic regime shift around 8,500 BP (Middle Holocene Altithermal). Second, contrast in the size distribution and density of quartz dust may also be linked to shifts in climate during the deposition of each unit. Furthermore, the quartz dust could be coming from a regional rather than a local source as a result of extended periods of aridity as has been suggested elsewhere by Forman et al. 2001 and Wood et al. 2002. However, the change in sedimentation of alluvium and eolian dust may also be caused by a change in sediment yield. It is possible that quartz dust was originally deposited on the upland soils that are the source of this alluvium long before it was deposited at the Gault site. Moreover, in thin section it is nearly impossible to differentiate quartz dust inherited from alluvium from dust deposited by eolian processes. Third, iron-staining of calcium carbonate nodules below and above the paleosol also offers a potential indicator for climate change. These stained nodules, however, could be the result of seasonal wetting and drying cycles that occurred on a regular basis at this site. In addition, the two types (core-stained and fully-stained) do occur together in the upper units (Units 5b and 6b) along with unstained carbonate nodules although the dominant type of nodules is fully-stained. This feature may reflect some change triggered by climate shifts, but, at this time there is not enough evidence to link these forms to such changes.

Nonetheless, micromorphological analysis at the Gault site has clarified a number of issues dealing with site formation processes. Several patterns emerge that may reflect depositional and post-depositional processes related to general shifts in climate over time at the Gault site. These patterns are summarized in Table 7. As a result, several conclusions can be made regarding site formation processes at the Gault site. First, the pond clay sediments of unit 3a underwent some soil formation processes, particularly in terms of calcium carbonate leaching. Second, soil formation processes are also evident in Unit 3b although the high concentration of carbonate and low concentration of redox features may indicate that these processes were not active for as long as in Unit 3a. Third, Units 4b and 4c were deposited during a period of higher sediment yield. Although there may have been a small erosional event between the deposition of these units, soil formation processes during this period involved both Units 4b and 4c. This is indicated by the significant increase of calcium carbonate accumulation and redoximorphic concentrations in Unit 4b compared to Unit 4c. Fourth, Units 5b, 6b, and 7b are all located above the paleosol. The lower degree of soil formation features found in these units is due not only to their younger age but also their higher position in the column profile which allowed for better drainage. Each unit does contain secondary carbonate features and redoximorphic concentrations. The development of carbonate features is fairly similar between units, while redox

Table 7. Site formation processes and general patterns observed in thin section.
Each category is classified by + (rare to few), ++ (few to frequent), +++ (frequent) or – (not present).

Stratigraphic Unit	Cultural Period	Site Formation Processes	Carbonate Accumulation	Redox Concentrations	Quartz Dust Concentration
7b	Archaic - Present	Soil Formation? Deposition	++	+	+++
6b	Archaic	Erosion? Soil Formation? Deposition	+++	++	++
5b	Archaic	Erosion? Soil Formation? Deposition	+++	+++	++
8,500 BP Climate Change: erosional event and truncation of paleosol					
4c	Folsom - Angostura	Soil Formation Deposition	++	++	+++
		Possible erosional event			
4b		Deposition	+++	+++	++
3b	**Erosional event**				
	Clovis	Soil Formation Deposition	+++	+	+++
3a	**Colluvial deposition slightly upslope from main column.**				
	Clovis	Soil Formation Deposition	+	++	+++
1 and 2		Deposition	-	+	-
Bedrock	**Erosional event that scoured limestone surface.**				

concentrations steadily decrease with elevation resulting in very few redox concentrations in Unit 7b. This can be accounted for by their age difference.

Nonetheless, of the paleoenvironmental sequences discussed for Central Texas, the model produced from the stable carbon isotope analysis (Nordt et al. 1994) most closely correlates with the site formation data from the Gault site. The model of Nordt et al. 1994 and data from this analysis at the Gault site suggest a dry period during the formation of Units 3a and 3b. According to the archaeological record, this occurred during the Clovis period. Haynes (1991, 1993) and Ferring (2001) also suggest there was lower precipitation and some drought conditions during the Paleoindian period compared to earlier and later periods. Stratigraphic and geomorphic evidence in southeastern Arizona indicate that water table levels dropped significantly around 10,900 BP (Haynes 1991, 1993). Furthermore, this correlates with the Oxygen isotope record (decrease in δ^{18} levels) during the colder and drier Younger Dryas period that occurred in northern Europe ca. 10,750 BP. At the Aubrey site (Ferring 2001), geochemical, botanical, and faunal data imply that the environment was cool and dry from the end of the Pleistocene until the Clovis period and possibly later. Such a climate change has obvious implications for human adaptation during this period and it appears that this shift in climate was not only a regional phenomena but also a global climate trend.

CHAPTER VI

CONCLUSIONS

Micromorphological investigations at the Gault site have clarified a number of geoarchaeological issues and demonstrated how micromorphology can be useful at open-air Paleoindian sites in North America. This study has clarified not only the four research objectives: 1) origin of calcium carbonate nodules, 2) impact of groundwater, 3) post-depositional processes, and 4) archaeological evidence in thin section, but it has also provided evidence for paleoenvironmental change based on sedimentation rates, eolian deposition of quartz dust, and distribution and nature of iron-stained calcium carbonate nodules. In addition, a summary of formation processes at the Gault site can be found in Appendix D. This study has illustrated how micromorphological analysis can be applied at open-air Paleoindian sites and what type of research questions can be investigated.

The conclusions based on this micromorphological analysis of sediments from the Gault site are as follows:

1. Particle size analysis on a non-carbonate free, carbonate-free, and carbonate- and clay-free basis suggests that calcium carbonate has significantly leached from Units 3a and 4c.
2. Based on micromorphological evidence, most calcium carbonate nodules appear to be pedogenic (i.e., filaments, pore coatings, and nodules), although some are lithogenic (inherited) which were deposited by alluvial and colluvial processes.

However, this issue needs to be corroborated with stable carbon isotope analysis of these sediments.

   a. Calcium carbonate accumulation was greater in Units 3b, 4b, 5b, and 6b compared to Units 3a, 4c, and 7b. This is due to leaching of calcium carbonate.
   b. Units 3b and 4b have more developed forms of carbonate accumulation than Units 5b and 6b which reflects their relative age difference.

3. Micromorphological analysis suggests that groundwater had a significant impact on sediments and the preservation of organic materials.
   a. Micromorphological evidence of striated b-fabric in Unit 3a suggests that this unit perched the existing water table (episaturation).
   b. Based on the distribution of redoximorphic features in thin section, the water table had a greater impact on sediments below unit 4c because of the perched water table compared to units 5b, 6b, and 7b, which were better drained because the water table rarely rose into these sediments.
   c. Groundwater had a negative impact on the preservation of organic material due to continual cyles of wetting and drying.
   d. Groundwater movement was predominantly lateral during periods of high discharge and during periods of low discharge water seeped upward from a perched water table (episaturation).
4. Micro-bioturbation is evident in all stratigraphic units and has destroyed evidence for occupation surfaces, muddled clear stratigraphic breaks, and broken charcoal and

organic matter into small fragments which are dispersed throughout the matrix of each unit. However, charcoal dates from Unit 3a may suggest that this charcoal is the byproduct of modern burning.

5. Similarly, archaeological evidence is found in thin section (chert microdebitage, bone, charcoal), but this does not correlate with any distinct occupation surfaces because they have been destroyed by micro-bioturbation.
6. *Rabdotus* shell fragments found in Units 5b and 6b have been disturbed by post-depositional processes (i.e., burrowing, trampling).
7. Evidence for paleoenvironmental change may be reflected by the precipitation of calcium carbonate and mobilization of iron, changes in sedimentation rates and/or yields, deposition of quartz dust, and iron staining of calcium carbonate nodules. The precipitation of calcium carbonate and iron is the clearest micromorphological evidence for paleoenvironmental change, although these other types of data have potential for further testing.
8. Implications for the paleoenvironmental conditions from this analysis of sediments from the Gault site and data from stable carbon isotope analysis (Nordt et al. 1994) both suggest that the Paleoindian period was a period of low precipitation and periodic droughts. This dry period correlates well with evidence from a site in southeastern Arizona (where water tables dropped ca. 10,900 BP) and the oxygen isotope record (a decrease in δ^{18} levels ca 10,750 BP) during the Younger Dryas period in northern Europe (Haynes 1991, 1993). In addition, data from the Aubrey Site (Ferring 2001) also implies that the climate was cool and dry from the end of the

Pleistocene to the beginning of the Clovis period and possibly later. This may indicate not only a global climate trend during this period, but also that a Clovis-Age drought occurred at the Gault site.

GLOSSARY

(after Bullock et al. 1985 and Vepraskas 1996)

b-fabric Birefringence fabric. The micromass (fabric) as viewed under cross-polarized light. The characteristics of interference colors are described in terms of their orientation and distribution within the thin section.

Chambers A void shape that is characteristically elongated, cylindrical or arched with regular conformation, smoothed walls, and a uniform cross section.

Channels A void shape that is characteristically spherical and connected by channels (see above) with smoothed walls.

Fabric Spatial arrangement (shape, size, and frequency) of a sediment or soil composed of solid, liquid, and gaseous constituents.

Microstructure Porosity of the fabric examined at 5x magnification or higher including features such as earthworm channels and large aggregates.

Orthic An orthic pedofeature that appears to consist of the same material as the matrix (e.g., orthic calcium carbonate nodule).

Porostriated, granostriated, cross striated B-fabric oriented around a particular feature such as void (porostriated), coarse material (granostriated), or within the matrix at angles (cross striated).

Porphyric related distribution A dense groundmass with the coarse fraction scattered throughout the matrix as is characteristic of fine textured sediments.

Redoximorphic concentrations Redoximorphic features that occur as the result of the accumulation of iron-manganese oxides (Fe-Mn oxides). Features include nodules, concretions, masses, and pore linings.

Redoximorphic depletions Redoximorphic features that occur as the result of the reduction of iron (Fe II), have low chroma of ≤2, with values of ≥4 where Fe-Mn oxides and/or clay have been removed.

Redoximorphic features Features that result from the reduction, translocation, and oxidation of iron or manganese oxides in seasonally saturated soils.

Related distribution The distribution pattern between coarse and fine material.

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APPENDIX A

Field Description of Stratigraphic Units for Sampling Location 1 (Field descriptions by M. Waters)

Unit	Level	Lab #	TXT	(cm)	Field Color	Structure	Lower Contact	Contents	Calcium Carbonate	Redoximorphic Features
6b	1 2 3 4	D5341 D5342 D5343 D5344	SiC C C C	9	Dry: 10 YR 5/2 (Grayish brown) Wet: 10 YR 4/2 (Dark grayish brown)	Strong, coarse granular/ crumb	Abrupt	Rabdotus shells (many), whole and fragmented. Subrounded colluvial gravels (max. 14 cm). Rounded to subangular gravels (2-4 cm). Fire cracked rock and artifacts.		
5b	6b 7 8	D5347 D5348 D5349	C SiC SiC	15	Dry: 10 YR 6/2 (Light brownish gray) Wet: 10 YR 5/3 (Brown)	Strong, coarse granular	Abrupt	Artifacts. Rare, subangular to subrounded limestone colluvium. Few snails. Bones. Few roots. Root hairs.	Calcium carbonate nodules (2-5 cm). Thin dusting of calcium carbonate on bottom of artifacts and rocks.	Yellow mottles (10 YR 7/8), 10%, common, 2-5 mm, fine, distinct. Found on calcium carbonate nodules.
4c	9 10 11 12 13	D5350 D5351 D5352 D5353 D5354	SiC C C C C	25	Dry: 10 YR 5/2 (Grayish brown) Wet: 10 YR 4/2 (Dark grayish brown)	Strong, medium - coarse, subangular blocky structure	Transitional	Roots, root holes, artifacts, and few subangular to subrounded stones	Nodules (2-5 mm??), hard, and smaller nodules, (1 mm), softer. Only found on ped and fracture faces, particularly in lower half.	Yellowish brown mottles (10 YR 5/4), mostly in upper section, few to common, fine. At base, look like root tracks, faint.
4b	14 15 16 17	D5355 D5356 D5357 D5358	C C C SiC	20	Dry: 10 YR 6/2 (Light brownish gray) Wet: 10 YR 5/3 (Brown)	Moderate, fine, subangular blocky	Transitional	Occasional subrounded cobbles (1-4 cm). Roots.	Abundant nodules (1-10 cm), irregular, soft, and found on ped faces.	Yellow mottles similar to Unit 4c but more abundant and along 2-4 mm diameter root channels. Many and distinct. Root stains stop at contact with Bk1 (Unit 4c).
4b/3b	18 19	D5359 D5360	SiC CL	10						
3b	20 21 22	D5361 D5362 D5363	C C C	15	Dry: 10 YR 5/3 (Brown) Wet: 10 YR 4/2 (Dark grayish brown)	Moderate, medium, subangular blocky structure	Abrupt and smooth, genetically related to clays below.	Clovis artifacts, modern roots, and large flakes	Nodules (2-5 mm), hard, round and irregular. Common, fine, prominent, on ped surfaces and dusting of calcium carbonate on all sides of pebbles but thickness of bottom coating is up to 2mm. Coating thickest on underside of large flake. Concentration increases towards contact.	Iron mottles along root channels (strong brown 7.5 YR 5/8, moist), 5 mm, moderate, common, and extend from overlying unit.
3a	23 24	D5364 D5365	C C	20	Dry: 10 YR 6/2 (Light brownish gray) Wet: 10 YR 5/2 (Grayish brown)	Vertic, medium to coarse, strong, irregular subangular peds, some fine to medium wedges	Abrupt and smooth, genetically related to clays below.	Clay films. Slickensides on all ped surfaces. Artifacts have coatings on top or bottom.	Nodules (0.5-3 cm), hard, and along ped surfaces.	Iron mottles similar to Unit 3b but more diffuse and not along root channels. Common, distinct, along ped faces and coat stones.

Field Description of Stratigraphic Units for Sampling Location 3
(Field descriptions by C.T. Hallmark, L.P. Wilding, L.R. Drees, and TAMU Soil Microfabric Analysis Class of Spring 2000)

Horizon	Unit	Depth	Lab #	TXT	Field Color (Dry)	Structure	Boundary	Contents	Calcium Carbonate	Redoximorphic Features
A1	7b	0-10	6487	C	10 YR 2/1 (Black)	Moderate fine granular	Gradual smooth	Few fine roots, less than 1% irregular chert flakes that are randomly oriented relative to the surface, and less than 1% decomposing shells.		
A2	6b	10-24	6488	C	10 YR 3/1 (Very dark gray)	Moderate medium and fine granular	Clear smooth	Few fine roots, less than 1% irregular chert flakes that are randomly oriented relative to the surface, few irregular pebbles and cobbles of limestone, one fired limestone cobble, and less than 1% decomposing shells.		
Bk1	6b	24-38	3489	C	2.5 Y 3/2 (Very dark grayish brown)	Moderate fine and medium subangular blocky	Gradual smooth	Few fine roots, 20% coarse fragments, pebbles (40:60, limestone:chert). 20% shell fragments: some are intact and 5-20 mm.		
Bk2	5b	38-55	6490	SiC	10 YR 4/2 (Dark grayish brown)	Moderate fine and medium subangular blocky and angular blocky	Clear smooth	Few fine and coarse roots, 20% coarse fragments (1-5 cm), and few shell fragments. Chert fragments and flakes at all angles.	Few filaments and threads along ped faces.	
Bk3	5b	55-71	6491	SiC	10 YR 5/2 (Grayish brown)	Moderate fine subangular blocky and angular blocky	Abrupt smooth	Few fine and very fine roots. 28% coarse fragments including burned limestone and chert flakes (0.5-15 cm) and are at irregular angles.	Few fine filaments and threads along ped faces and in ped pores.	Common fine distinct yellowish brown (10 YR 5/6) and few fine distinct light brownish gray (10 YR 6/2) mottles. Mottles seem to be due to weathering of limestone fragments.
2Akb	4c	71-85	6492	C	2.5 Y 4/2 (Dark grayish brown)	Moderate fine and medium angular blocky	Clear smooth	Few fine and very fine roots, few intact gastropod shells, 17% coarse fragments of chert and limestone (most is burnt), and a few worked flakes at irregular angles.	Few fine filament and threads along ped surfaces and in ped pores.	Few diffuse redox features along pores.

Horizon	Unit	Depth	Lab #	TXT	Field Color (Dry)	Structure	Boundary	Contents	Calcium Carbonate	Redoximorphic Features
2Bkb1	4c	85-97	6493	C	2.5 Y 5/2 (Grayish brown)	Weak fine and medium subangular blocky	Clear wavy	Few fine and very fine roots, chert flakes at random angles, and 5% coarse fragments (equal amounts of limestone and chert; 1-5 cm).	Many fine and very fine carbonate coatings in ped pores. Many fine filaments and threads on ped surfaces. Chert fragments have thin carbonate coatings.	Common fine distinct olive yellow (2.5 Y 6/6) and common medium faint brown (10 YR 5/3) mottles.
2Bkb2	4b	97-124	6494	SiC	10 YR 6/2 (Light brownish gray)	Weak fine and medium subangular blocky	Abrupt wavy	Few fine and very fine roots, chert flakes at random angles, 5% coarse fragments (equal amount of limestone and chert), small flakes of charcoal noted at base of horizon (?), few MN films reacting with hydrogen peroxide.	Many fine and very fine carbonate coatings in ped pores. Many fine filaments and threads on ped surfaces. Thick carbonate coatings on coarse fragments and common large soft masses of carbonate.	Many medium faint pale brown (10 YR 6/3) and few fine distinct olive yellow (2.5 Y 6/6) mottles.
3Bkb	?	124-140	6495	SiCL	10 YR 5/4 (Yellowish brown)	Weak fine and medium subangular blocky	Clear wavy	Few fine and very fine roots. Cobbles have weakly indurated with an oxide rich weathering rind about 1 cm thick. 60% coarse fragments (40% cobbles, 20% gravels), limestone dominates, and limestone cobbles have lobate shape.	Many filaments and threads of carbonate along chert and limestone surfaces, common fine hard carbonate nodules, and few medium soft carbonate masses.	Common medium distinct yellowish brown (10 YR 5/6) and few medium distinct light brownish gray (10 YR 6/2) mottles. Depletions of 10 YR 6/2 along pores.
4BCkb1	1	140-150	6496	SiL	2.5 Y 7/6 (Yellow)	Weak medium subangular blocky	Clear wavy	Very few very fine roots. Thin common distinct organic coatings along root channels and in ped pores.	Few thin common 10 YR 5/6 areas from weathering of limestone.	Common fine faint brownish yellow (10 YR 6/6) mottles.
4BCkb2	1	150-165	6497	SiCL	2.5 Y 7/2 (Light gray)	Weak coarse subangular blocky	n/a	Very few very fine roots and pores have darkened organic linings.	Few 10 YR 5/6 areas from weathering of limestone. Many large soft masses of secondary carbonates, 1-3 mm rounded, and partially indurated limestone fragments.	

APPENDIX B

Particle Size Distribution and Calcium Carbonate % for Sampling Location 1 (Calcium Carbonate-Free Samples are Shaded and in Bold)

Sample	Unit	Level	Very Coarse Sand (2.0 – 1.0 mm)	Coarse Sand (1.0 - 0.5 mm)	Medium Sand (0.5 - 0.25 mm)	Fine Sand (0.25 - 0.10 mm)	Very Fine Sand (0.10 - 0.05 mm)	Total Sand (2.0 - 0.05 mm)	Coarse Silt (0.05 - 0.02 mm)	Fine Silt (0.02 - 0.002 mm)	Total Silt (0.05 - 0.002 mm)	Fine Clay (<0.0002)	Total Clay (<0.002 mm)	Texture	Calcium Carbonate Equivalent (%)
D5341	**6b**	1	1.9	1.5	1.4	1.9	3.1	9.8	6.3	33.9	40.2	13.0	50.0	SiC	-
D5342	**6b**	2	5.4	3.6	2.1	2.5	3.7	17.3	7.4	31.1	38.5	20.0	44.2	C	-
D5343	**6b**	3	5.0	4.5	2.2	2.5	3.8	18.0	7.5	30.9	38.4	22.4	43.6	C	44.9
G5343	**6b**	**3**	**1.3**	**0.7**	**0.5**	**0.7**	**1.7**	**4.9**	**15.6**	**23.4**	**38.9**	**44.3**	**56.2**	**C**	**0**
D5344	**6b**	4	3.1	3.1	2.2	2.8	3.9	15.1	6.4	32.3	38.7	23.0	46.2	C	-
D5347	**5b**	6b	3.5	2.1	1.4	2.0	3.4	12.4	5.3	34.5	39.8	23.0	47.8	C	-
D5348	**5b**	7	3.3	2.5	1.7	2.2	3.4	13.1	4.9	36.2	41.1	22.7	45.8	SiC	44.4
G5348	**5b**	**7**	**0.8**	**0.5**	**0.4**	**0.7**	**1.8**	**4.2**	**17.5**	**22.1**	**39.6**	**45.4**	**56.2**	**C**	**0**
D5349	**5b**	8	2.5	1.4	1.0	2.0	3.3	10.2	5.3	37.0	42.3	22.5	47.5	SiC	-
D5350	**4c**	9	2.0	1.1	0.9	1.7	2.9	8.6	4.2	36.4	40.6	26.0	50.8	SiC	-
D5351	**4c**	10	2.7	1.5	1.0	1.7	3.1	10.0	5.3	31.7	37.0	29.9	53.0	C	35.7
G5351	**4c**	**10**	**0.8**	**0.5**	**0.4**	**0.8**	**2.1**	**4.6**	**11.4**	**24.1**	**35.4**	**48.9**	**60.0**	**C**	**0**
D5352	**4c**	11	1.4	0.9	0.9	1.6	3.0	7.8	4.8	31.6	36.4	32.9	55.8	C	-
D5353	**4c**	12	1.2	1.3	1.0	1.7	3.0	8.2	4.6	32.6	37.1	30.0	54.7	C	30.1
G5353	**4c**	**12**	**0.9**	**0.4**	**0.3**	**0.7**	**2.4**	**4.7**	**12.1**	**23.7**	**35.8**	**48.5**	**59.5**	**C**	**0**
D5354	**4c**	13	1.9	1.5	1.3	1.8	2.9	9.4	4.5	32.8	37.3	27.5	53.3	C	-
D5355	**4b**	14	2.6	2.0	1.6	2.0	3.1	11.3	3.1	34.2	37.2	23.6	51.5	C	-
D5356	**4b**	15	2.5	1.8	1.2	1.8	3.1	10.4	5.1	34.2	39.2	21.8	50.4	C	48.3
G5356	**4b**	**15**	**0.2**	**0.2**	**0.2**	**0.6**	**1.8**	**3.0**	**16.7**	**23.6**	**40.3**	**46.2**	**56.7**	**SiC**	**0**
D5357	**4b**	16	2.7	1.8	0.9	1.8	3.7	10.9	5.3	34.5	39.7	25.7	49.4	C	-
D5358	**4b**	17	3.4	2.4	2.1	2.5	3.5	13.9	5.3	34.7	40.0	20.7	46.1	SiC	-
D5359	**4b/3b**	18	3.9	2.3	2.1	3.3	4.0	15.6	8.2	32.7	41.0	20.6	43.4	SiC	45.6

Sample	Unit	Level	Very Coarse Sand (2.0 – 1.0 mm)	Coarse Sand (1.0 - 0.5 mm)	Medium Sand (0.5 - 0.25 mm)	Fine Sand (0.25 - 0.10 mm)	Very Fine Sand (0.10 - 0.05 mm)	Total Sand (2.0 - 0.05 mm)	Coarse Silt (0.05 - 0.02 mm)	Fine Silt (0.02 - 0.002 mm)	Total Silt (0.05 - 0.002 mm)	Fine Clay (<0.0002)	Total Clay (<0.002 mm)	Texture	Calcium Carbonate Equivalent (%)
G5359	**4b/3b**	**18**	**0.2**	**0.2**	**0.1**	**0.5**	**2.3**	**3.3**	**17.2**	**23.9**	**41.1**	**44.3**	**55.6**	**SiC**	**0**
D5360	**4b/3b**	19	5.6	4.0	3.4	3.4	3.9	20.3	8.2	32.2	40.4	19.0	39.3	CL	-
D5361	**3b**	20	6.0	4.0	3.0	3.1	3.7	19.8	7.3	32.1	39.4	22.5	40.8	C	-
D5362	**3b**	21	6.0	3.2	2.9	3.6	4.1	19.8	8.0	31.4	39.4	22.3	40.8	C	41.9
G5362	**3b**	**21**	**0.2**	**0.2**	**0.2**	**0.5**	**2.5**	**3.6**	**15.7**	**24.6**	**40.3**	**44.5**	**56.1**	**SiC**	**0**
D5363	**3b**	22	3.3	3.6	2.9	2.7	3.5	16.0	7.0	31.8	38.8	20.2	45.2	C	-
D5364	**3a**	23	3.2	2.7	1.7	1.6	3.5	12.7	7.8	28.8	36.6	24.5	50.7	C	-
D5365	**3a**	24	1.1	0.9	0.8	1.6	1.7	6.1	8.5	27.3	35.8	32.0	58.1	C	3.4
G5365	**3a**	**24**	**0.3**	**0.3**	**0.5**	**1.2**	**2.9**	**5.2**	**9.9**	**25.5**	**35.4**	**47.8**	**59.4**	**C**	**0**

Particle Size Distribution, Calcium Carbonate Equivalent, Organic Carbon, pH, and COLE for Sampling Location 3

Sample	Horizon	Unit	Depth	Very Coarse Sand (2.0 – 1.0 mm)	Coarse Sand 72.02– 0.5 mm)	Medium Sand (0.5 – 0.25 mm)	Fine Sand (0.25 – 0.10 mm)	Very Fine Sand (0.10 – 0.05 mm)	Total Sand (2.0 – 0.05 mm)	Fine Silt (0.02 – 0.002 mm)	Total Silt (0.05 – 0.002 mm)	Fine Clay (<0.0002)	Total Clay (<0.002 mm)	Texture	Calcium Carbonate Equivalent (%)
6487	A1	**7b**	0-10	2.5	1.9	1.5	2.4	3.9	12.2	30.0	36.2	26.5	51.6	C	25.1
6488	A2	**6b**	10-24	6.1	4.2	2.3	3.2	4.3	20.1	29.3	34.9	24.5	45.0	C	39.5
3489	Bk1	**6b**	24-38	4.3	4.2	2.7	4.0	5.5	20.7	31.0	38.8	21.7	40.5	C	53.8
6490	Bk2	**5b**	38-55	3.6	2.8	2.4	3.5	5.2	17.5	33.3	40.1	22.6	42.4	SiC	50.5
6491	Bk3	**5b**	55-71	2.5	2.3	2.1	3.5	5.2	15.6	34.2	40.4	20.1	44.0	SiC	56.8
6492	2Akb	**4c**	71-85	1.7	1.4	1.2	2.8	4.6	11.7	32.6	38.8	28.0	49.5	C	43.8
6493	2Bkb1	**4c**	85-97	1.6	1.5	1.9	3.5	4.7	13.2	33.2	38.8	23.9	48.0	C	51.7
6494	2Bkb2	**4b**	97-124	2.0	2.2	2.9	4.7	5.2	17.0	35.0	40.6	20.5	42.4	SiC	58.5
6495	3Bkb	**?**	124-140	3.1	2.6	3.0	4.9	5.8	19.4	41.1	48.7	20.2	31.9	SiCL	59.7
6496	4BCkb1	**2**	140-150	0.7	0.9	1.3	3.2	5.6	11.7	55.2	64.8	17.3	23.5	SiL	72.6
6497	4BCkb2	**2**	150-165	0.4	0.9	1.3	2.6	3.9	9.1	55.8	60.8	18.7	30.1	SiCL	72.8

Sample	Horizon	Unit	Depth	Organic Carbon (%)	pH	COLE
6487	A1	**7b**	0-10	2.58	7.8	0.095
6488	A2	**6b**	10-24	2.03	8.0	0.066
3489	Bk1	**6b**	24-38	1.11	8.0	0.059
6490	Bk2	**5b**	38-55	1.28	8.0	0.035
6491	Bk3	**5b**	55-71	0.99	8.1	0.034
6492	2Akb	**4c**	71-85	0.70	8.0	0.073
6493	2Bkb1	**4c**	85-97	0.63	8.2	0.045
6494	2Bkb2	**4b**	97-124	0.50	8.2	0.028
6495	3Bkb	**?**	124-140	0.49	8.2	0.047
6496	4BCkb1	**2**	140-150	0.26	8.3	0.036
6497	4BCkb2	**2**	150-165	0.33	8.2	0.03

APPENDIX C

THIN SECTION DESCRIPTIONS

Sampling Location 1

Unit 3a

Sample Block #9, Thin Sections 9A, 9B, 9C: Unit 3a is a clay with a few grains of quartz, calcite, chert, chalcedony, and limestone (porphyric related distribution). Quartz and limestone grains are rounded and grains of calcite and chert are both rounded and angular. Quartz is mainly silt- to sand-size and found throughout the matrix and limestone grains are iron-stained. Voids found in these samples include channels, vesicles, vughs, and chambers. Orange redoximorphic concentrations with diffuse boundaries are found scattered throughout the matrix. The fabric appears oriented along macropores and skeleton grains. In thin section, this is visible in the form of oriented clay "halos" along voids and around grains (see Chapter V). Disconnected voids indicate that this sediment has been moderately bioturbated. On the edges of chert flakes, matrix material appears to have attached to edges of these flakes as a result of swelling of the sample during impregnation. Calcium carbonate nodules are found throughout the matrix and along macropores with sharp and diffuse boundaries.

Fine Fraction (Matrix):

- Redoximorphic concentrations:
  - Orange
  - Scattered throughout the matrix
  - Diffuse boundaries
- Carbonates:
  - Coatings do not appear to be seen on chert flakes because it appears that matrix has attached to chert edges due to swelling or during sample impregnation.
  - Carbonates are found throughout the matrix and along macropores
  - Sharp and diffuse boundaries
  - Secondary carbonates stain the edges of chert flakes and are now dissolving out

Coarse Fraction (Inclusions):

- Quartz is mainly fine and medium and found throughout the matrix
- Clasts:
  - Quartz, calcite, chert, chalcedony, and limestone
  - Quartz, calcite, chert, and limestone are rounded.
  - Calcite and chert are angular
  - Shell fragment from limestone
  - Piece of sandstone (hammer? Animal/human track in?)

Microstratigraphy:

- Microstructure is subangular blocky but some domains are prismatic
- Moderately to poorly sorted
- Voids:
  - Channels, vesicles, vughs, and chambers
- Porphyric
- Granostriated, porostriated, and parallel striated fabric due to shrink-swell of clays
- The skeleton grains do not appear oriented but the fabric appears oriented along macropores and skeleton grains
- Bioturbation:
  - Disconnected voids

Archaeological Evidence:

- Three large chert artifacts and chert microdebitage
- Piece of sandstone (hammer? Animal/human track in?)

Boundary Between Unit 4b and Unit 3b

Sample Block #7, Thin Sections 7E, 7F: The boundary between Unit 3b (clay) and Unit 4b (silty clay) contains grains of quartz, calcite, chert, chalcedony, and limestone were found in these samples (porphyritic related distribution). Quartz, calcite, chert, and limestone appear to be rounded although some chert is found in large, angular pieces that are likely to be pieces of microdebitage. Some of the subrounded chert grains could be part of the sediment. Some limestone grains are iron stained. Most of the quartz appears to be silt-sized and there seems to be more skeletal grains in these thin sections than in overlying thin sections 7C and 7D. The type of voids found in these samples include channels, vesicles, vughs, and chambers. The presence of disconnected voids indicate that there has been moderate bioturbation in these units. Redoximorphic concentrations are present in the matrix with diffuse boundaries and appear to be more concentrated in these lower samples than in the overlying thin sections of sample block 7 (A, B, C, D). Orthic carbonate nodules are found throughout the matrix and along macropores and have sharp and diffuse boundaries. The boundary is very diffuse and not discernable in thin section.

Fine Fraction (Matrix):

- Silty quartz matrix
- Redoximorphic concentrations:
  - Masses
  - Much more concentrations than in the overlying thin sections 7A, 7B, 7C, and 7D
  - Found throughout the matrix
  - Have diffuse boundaries

- Most carbonates are iron-stained
- Several large carbonates are breaking apart into smaller fragments and are not iron-stained
- Iron-staining of carbonates is not uniform because some carbonates are stained more densely than other (i.e., thicker and deeper orange-brown)
- Iron-stained carbonates are mostly stained in the center of the nodule with an outer unstained carbonate layer surrounding
- Some iron-stained carbonates are iron-stained to the edge of the nodule
- Matrix is iron-stained
- Iron-stained pore with a hypoferan and some possible organic matter
- Macropores are heavily stained with iron

- <u>Carbonates</u>:
  - Nodules are very dense
  - Appear to be in various stages of formation
  - Root voids filling up with carbonate
  - Carbonate hypocoatings in the matrix
  - Several large carbonates are breaking apart into smaller fragments and are not iron-stained
  - Carbonate nodules are orthic with sharp and diffuse boundaries and found throughout the matrix and along macropores.
  - Some carbonates have clay staining in the center of the nodules
  - It does not appear that carbonate coatings are seen on chert flakes.
- Possible organic material, charcoal, or humified organic material
- Some clay fillings that are birefringent

Coarse Fraction (Inclusions):

- More silty quartz than Unit 3a
- <u>Clasts</u>:
  - Quartz, calcite, chert, chalcedony, and limestone
  - Quartz, calcite, chert, and limestone are rounded
  - Chert is found in large pieces, angular, and has a crackley appearance.
  - Most of the quartz appears fine
  - There seems to be more skeletal grains than Samples 7C and 7D.
  - Some of the subrounded chert grains could be part of the sediment
  - Rounded sand-size limestone clast
  - Two shell fragments
  - Couple of sand-size quartz grains

Microstratigraphy:

- Some domains have subangular blocky microstructure and others appear more prismatic
- Moderately sorted
- Porphyric

- Voids:
  - Channels, vesicles, vughs, and chambers
  - Channels are mainly perpendicular to the surface
- Skeleton grains do not appear to be oriented
- Bioturbation is evident by disconnected voids

Archaeological Evidence:
Two chert flakes that are archaeological and lying fairly horizontal to the surface (only in 7F)

Unit 4c

Sample Block #7, Thin Sections 7C, 7D: Unit 4c is a clay with few grains in the matrix (porphyric related distribution). Grains present in this sample include quartz, calcite, chert, chalcedony, limestone, and a shell fragment. Quartz, chalcedony, chert, and limestone grains are rounded although some chert fragments are also angular. Fine, silt-sized quartz grains are distributed throughout the matrix. The types of voids found in this sample include channels, vesicles, vughs, and chambers. Channel voids in this fabric are oriented mainly perpendicular to the surface and the presence of disconnected voids indicates moderate bioturbation. Redoximorphic concentrations found in the matrix have diffuse boundaries and are dark orange to dark orange-red. These redox concentrations appear to be more concentrated in thin section 7C than in overlying thin section 7B. Chert flakes. Calcium carbonate nodules found throughout the matrix and along macropores have both sharp and diffuse boundaries.

Fine Fraction (Matrix):
- There are few grains in this sample
- Silty quartz matrix
- Redoximorphic concentrations:
  - Masses
  - Dark orange to dark orange-red
  - Found throughout the matrix
  - Have diffuse boundaries
  - Redox concentrations appear to be more concentrated than in samples directly above (Thin sections 7A and 7B)
  - Iron-staining of carbonates also appears lighter (lighter orange) and less dense with increasing elevation compared to underlying samples
  - Some large carbonates are iron-stained

- Carbonates:
  - Carbonate nodules
  - Have sharp and diffuse boundaries
  - Found throughout the matrix and along macropores
  - It does not appear that carbonate coatings on chert flakes
  - Fewer carbonates than thin sections 7E and 7F below
  - Carbonate density decreases as elevation increases in the column
  - Some pores have carbonate infillings
  - Carbonates break up into smaller pieces and appear to be dissolving away in thin section 7C
- Some small concentrations of organic matter
- One Sesquioxide

Coarse Fraction (Inclusions):
- Fine quartz is distributed throughout the matrix.
- Clasts:
  - Quartz, calcite, chert, chalcedony, and limestone in addition to a possible fragment of shell
  - Quartz, chalcedony, chert, and limestone are rounded
  - Chert fragments are angular
  - Large round chert clast on top of thin section 7D

Microstratigraphy:
- Microstructure is subangular blocky
- Moderately sorted
- Voids:
  - Channels, vesicles, vughs, and chambers
- Porphyric
- Similar to Samples 7A and 7B, skeleton grains are not oriented but the fabric has channels that are mainly perpendicular to the surface.

- Bioturbation:
  - Disconnected voids

Archaeological Evidence:
- None

Unit 4c

Sample Block #7, Thin Sections 7A, 7B: This clay has few skeletal grains (porphyric related distribution) although fine quartz is found distributed throughout the matrix. Grains of quartz, calcite, chert, chalcedony, and limestone are also found in the matrix and quartz, calcite, chalcedony, and limestone grains are rounded. Chert grains are angular and limestone grains are iron stained. Similar to the other thin section from sample block #7, channel voids are oriented perpendicular to the surface. Other types of voids found in these thins sections include vesicles, vughs, and chambers. Moderate bioturbation is evident from the presence of disconnected voids. Redoximorphic concentrations in the matrix have diffuse boundaries and are orange to dark orange-red. Calcium carbonate nodules have both sharp and diffuse boundaries and are found throughout the matrix and along macropores.

Fine Fraction (Matrix):

- Fine micromass
- More grainy matrix than underlying units
- <u>Redoximorphic concentrations</u>:
  - Masses
  - Orange to dark orange-red
  - Found throughout the matrix
  - Diffuse boundaries
  - Moderate iron staining and less than samples below
  - Staining of carbonates is lighter
  - Some iron hypocoatings
- <u>Carbonates</u>:
  - Less carbonates compared to samples below (Thin sections 7C, 7D)
  - Calcium carbonate nodules have sharp and diffuse boundaries
  - Found throughout the matrix and along macropores.
  - Some are dissolving into the matrix
  - Some are especially large with diffuse boundaries
  - Large carbonates that are breaking apart have medium orange iron staining in the center
  - Some carbonate hypocoatings
  - Carbonates have diffuse boundaries
  - It does not appear that there are carbonate coatings on chert flakes

Coarse Fraction (Inclusions):

- This unit has few skeletal grains
- Fine quartz is distributed throughout the matrix
- <u>Clasts</u>:
  - Quartz, calcite, chert, chalcedony, and limestone
  - Quartz, calcite, chalcedony, and limestone are rounded
  - Chert is angular and limestone is reddened
  - Piece of limestone seems to be weathering out
  - Rounded limestone clast
  - Squarish quartz grain

Microstratigraphy:

- Microstructure is subangular blocky
- Porphyric
- <u>Voids</u>:
  - Channels, vesicles, vughs, and chambers
  - Voids are smaller and finer than samples below; there are no large vughs
- Skeleton grains do not show any orientation
- Some channels and planes are oriented perpendicular to the surface

- Modern roots
- <u>Bioturbation</u>:
  - Biomatter can be found in vughs (more than underlying samples)
  - Root matter than samples below (more than underlying samples)
  - Disconnected voids.

Archaeological Evidence:

- Possible piece of microdebitage of chalcedonic chert that is triangular
- Bone fragment

Boundary between Unit 4c and Unit 4b

Sample Block #8, Thin Sections 8A, 8B, 8C: This clay unit contains grains of quartz, calcite, chert, chalcedony, and large grains of limestone (porphyric related distribution). The quartz, chert, and limestone are mostly rounded but some chert grains and all of the calcite grains are angular. Fine quartz grains are distributed throughout the matrix. Some chalcedony, limestone, and chert grains are reddened with iron. Voids in these samples include a mixture of channels, vesicles, vughs, and chambers and channel avoids are predominantly oriented perpendicular to the surface. Disconnected voids indicate the presence of moderate bioturbation. Redoximorphic concentrations found throughout the matrix are orange and have sharp and diffuse boundaries. Calcium carbonates nodules with sharp and diffuse boundaries are found throughout the matrix and along macropores.

Fine Fraction (Matrix):

- <u>Redoximorphic concentrations</u>:
  - Concretions and masses
  - Orange
  - Found throughout the matrix
  - Sharp and diffuse boundaries

- Carbonates:
  - Could be on chert flakes in Sample 8A but it is unclear whether they are on Sample 8B and there is no evidence for coatings in Sample 8C
  - Carbonates found throughout the matrix and along macropores
  - Sharp and diffuse boundaries

Coarse Fraction (Inclusions):
- Fine quartz is distributed throughout the matrix
- Clasts:
  - Quartz, calcite, chert, chalcedony, and limestone
  - Quartz, chert, and limestone are rounded
  - Chert and calcite are angular
  - Limestone clasts are large and appear to be heated ???
  - Chalcedony and chert appears reddened with iron

Microstratigraphy:
- Poorly sorted
- Voids:
  - Channels, vesicles, vughs, and chambers
- Porphyric
- Skeleton grains are not oriented but the fabric has channels that are perpendicular to the surface

- Bioturbation is evident by disconnected voids

Unit 4c

Sample Block #5, Thin Sections 5A, 5B, 5C: The clay matrix of this sample appears darker than the overlying and underlying units. This may be attributed to a higher amount of organic matter as this unit is part of the paleosol. This sample contains grains of quartz, calcite, chert, chalcedony, and limestone that are rounded although some chert fragments are angular and likely pieces of microdebitage. Limestone clasts are reddened by iron staining. Fine quartz is distributed throughout the matrix. The type of voids found in these thin sections include channels, vesicles, vughs, chambers, and some parts of the fabric are spongy. Disconnected voids indicate moderate bioturbation. Redoximorphic concentrations found throughout the matrix are dark orange-yellow and have diffuse boundaries. Orthic calcium carbonate nodules are throughout the matrix and along macropores. These nodules have both sharp and diffuse boundaries. It is unclear whether carbonate coatings occur on chert flakes in thin section but there is some evidence of their presence.

Fine Fraction (Matrix):

- Crackly matrix
- Matrix is coarser than Unit 4b with more quartz silt
- More massive and compact than Unit 4b
- Some parts of the fabric are spongy
- Fine micromass
- Redoximorphic concentrations:
  - Masses are dark orange-yellow
  - Diffuse boundaries
  - Found throughout the matrix
  - Carbonates are iron stained: some are only stained in the core and others are stained throughout the entire nodule
  - Yellow-orange staining is more prominent in matrix
  - Iron-staining decreases with elevation
- Carbonates:
  - Nodules are observed throughout the matrix and along macropores
  - Nodules have both sharp and diffuse boundaries
  - Possible carbonate coatings are found on chert flakes
  - Carbonate hypocoatings
  - Some large carbonates are dissolving and breaking up into smaller carbonates
  - Compound carbonate nodules
  - Not as cemented as Unit 4b
  - Less carbonates than unit 4b

Coarse Fraction (Inclusions):

- Fine quartz is distributed throughout the matrix.
- Clasts:
  - Quartz, calcite, chert, chalcedony, and limestone
  - Shell fragment
  - Quartz, calcite, chert, and limestone are rounded.
  - Limestone clasts are reddened (redox)
  - Larger quartz grains (sand-size) than underlying units
  - Large clast in top of block may be colluvial

Microstratigraphy:

- Microstructure is subangular blocky
- Voids:
  - Channels, vesicles, vughs, chambers
- Moderately to poorly sorted
- Porphyric

- Modern roots

- Yellow splotchy material: phosphatic or apathite?
- Bioturbation:
  - Skeleton grains and the fabric do not appear to be oriented
  - Disconnected voids
  - Modern roots broken up
  - Organic matter is churned up
  - Channel voids contain biomatter (fecal material)

Archaeological Evidence:
- Chert flakes are archaeological and some have a "crackley" appearance.
- Two chert flakes are lying parallel to the surface
- One chert flake is perpendicular to the surface
- Ash rhombs
- Piece of burned wood

Boundary between Unit 5b and Unit 4c

Sample Block #6, Thin Sections 6A, 6B, 6C: In comparison to Sample blocks 4 (Unit 5b) and 5 (Unit 4c), this sample looks very choppy. This sample includes quartz, calcite, chert, chalcedony, and limestone in addition to a possible shell fragment. Quartz, calcite, chert, chalcedony, and limestone are rounded. Some grains of quartz, calcite, and chert are angular. The limestone clasts are reddened by iron. In general, quartz is small, scarce, and subrounded. This sample is poorly sorted and porphyric. Voids include channels, vesicles, vughs, and chambers. Redox concentrations are dark yellow-orange to orange. They are found throughout the matrix and have diffuse boundaries. There is no orientation of skeleton grains or fabric. Bioturbation is evident by disconnected voids, channels, and the presence of fecal pellets. Calcium carbonate coatings were not found on chert flakes. Carbonate nodules are found in the matrix and along macropores with sharp and diffuse boundaries.
Boundary:

Fine Fraction (Matrix):
- In comparison to Units 5b and 4c, this fabric looks really choppy
- Redox concentrations:
  - Masses
  - Dark yellow-orange to orange
  - Found throughout the matrix
  - Diffuse boundaries
- Carbonates:
  - Coatings were not found on chert flakes
  - Nodules are found in the matrix and along macropores
  - Nodules have sharp and diffuse boundaries

Coarse Fraction (Inclusions):
- Clasts:
  - Quartz, calcite, chert, chalcedony, and limestone
  - Possible shell fragment
  - Quartz, calcite, chert, chalcedony, and limestone are rounded
  - Some grains of quartz, calcite, and chert are angular
  - Limestone clasts appear to have been weathered
  - Quartz is small, scarce, and subrounded

Microstratigraphy:
- Poorly sorted
- Porphyric
- Voids:
  - Channels, vesicles, vughs, and chambers

- Bioturbation:
  - No orientation of skeleton grains or fabric
  - Disconnected voids and channels
  - Presence of fecal pellets

Archaeological Evidence:
- Chert flakes and microdebitage

Unit 5b

Sample Block #4, Thin Sections 4A, 4B: Two thin sections were made from this sample. In general, this sample the matrix appears grainier in thin section than Sample 3 (Unit 6b). It contains quartz, calcite, chert, chalcedony, and limestone. No shell or fossils were observed. The quartz, calcite, chalcedony, and limestone grains are rounded while some quartz grains and one grain of chert is angular. The limestone also shows some reddening due to iron staining. Fine quartz is also distributed throughout the matrix. This sample is poorly sorted and is porphyric. Channels, vesicles, vughs, and chambers appear throughout the matrix. Redox concentrations are present in the form of masses and pore linings that are lighter orange than the redox concentrations observed in Sample 3. Some are also more yellow and dark orange. They are found throughout the matrix and along macropores. In addition, iron-staining is seen within carbonate nodules and a little less frequently than unit 6b. Neither skeleton grains or fabric appear oriented and bioturbation is evident by disconnected voids. Orthic carbonates are found in the matrix and along macropores with sharp and diffuse boundaries. Chert flakes in this sample do not have carbonate coatings.

Fine Fraction (Matrix):

- Silty quartz matrix
- Matrix appears grainier in thin section than Sample 3 (Unit 6b).
- Redoximorphic concentrations:
  - Masses and pore linings
  - Found throughout the matrix and along macropores
  - Most are lighter orange than the concentrations in Unit 6b
  - Some are also yellow or dark orange
  - Iron staining is more prevalent in the matrix
- Carbonates:
  - Found in the matrix and along macropores
  - Have sharp and diffuse boundaries
  - Some carbonates look very different from the matrix but could have formed in place and are light gray
  - Less abundant than underlying units
  - Some carbonates are lightly stained
  - Many appear to be in the early stages of formation with little staining
  - Pores filling up with carbonates are found
  - Coatings were not found on chert flakes

Coarse Fraction (Inclusions):

- Fine quartz is also distributed throughout the matrix
- Quartz, calcite, chert, chalcedony, and limestone
- No shell or fossil
- Clasts:
  - Quartz, calcite, chalcedony, and limestone grains
  - Most clasts are rounded
  - Some quartz grains and one grain of chert is angular
  - Several shell fragments are present
  - Several large round limestone clasts; possible colluvium

Microstratigraphy:

- Microstructure is subangular blocky
- Poorly sorted
- Porphyric
- Voids:
  - Channels, vesicles, vughs, and chambers appear throughout the matrix.

- Blotchy yellow stuff- iron rich clay??
- Modern roots

- <u>Bioturbation</u>:
  - Differences in porosity
  - Neither skeleton grains or fabric appear oriented
  - Disconnected voids
  - Broken up plant material
  - Spongy fabric

Archaeological Evidence:
- Chert flakes and microdebitage
- Possible piece of burnt wood?

Unit 6b

Sample Block #3, Thin Sections 3A, 3B, 3C: Three thin sections were made from this unit. This sample contains quartz, calcite, chert, chalcedony, and limestone grains in addition to fossil and shell fragments in a poorly sorted matrix and porphyric fabric. The quartz, calcite, chalcedony, and limestone grains are predominantly rounded, while the chert grains are mostly angular, although some grains are rounded. Some limestone fragments are reddened with iron and fine quartz appears to be distributed throughout the matrix. The type of voids observed include channels, vesicles, vughs, chambers, and planes and void distribution appears to be random. Redoximorphic concentrations include masses and nodules that are common throughout the matrix and along channels. They are dark orange-brown to yellow in color and nodules have diffuse boundaries. Redox concentrations occur along macropores and within pedogenic carbonate nodules. Oxidized iron concentrations are also evident in calcite and chert grains. Bioturbation is evident from the presence of disconnected voids and there is no orientation of skeleton grains or fabric. Chert flakes found in this sample do not have carbonate coatings. Carbonates found in the matrix and along macropores have diffuse boundaries.

Fine Fraction (Matrix):
- Fabric is spongy; more spongy than any unit
- <u>Redoximorphic concentrations</u>:
  - Masses and nodules are common throughout the matrix and along channels
  - Concentrations are dark orange-brown to yellow
  - Nodules have diffuse boundaries
  - Concentrations occur along macropores
  - Staining is found inside a few carbonate nodules
  - Calcite and chert grains exhibit some staining
  - Iron staining is more localized in the matrix than unit below and darker

- Carbonates:
  - Located in the matrix and along macropores
  - Some have diffuse boundaries and others have distinct boundaries that look similar to those found in Unit 5b
  - Nodules are found in various sizes
  - Most carbonates are not iron-stained
  - There are less carbonates in this unit than see in Unit 5b
  - Coatings were not found on chert flakes

Coarse Fraction (Inclusions):

- Quartz silt that is found throughout the matrix is finer than the quartz silt found in Unit 5b
- Clasts:
  - Quartz, calcite, chert, chalcedony, limestone, fossil and shell fragments
  - Larger clasts are up to 1 cm in diameter and rounded
  - Some chert clasts are rounded
- *Rabdotus* shell fragments:
  - Shell fragments are very abundant in this unit
  - Shells are mostly broken up and some are broken in place
  - Some shells lie at various angles and appear to be churned up
  - There are few intact shells
  - Some shells appear to be weathering from their center

Microstratigraphy:

- Microstructure is subangular blocky
- Voids:
  - Channels, vesicles, vughs, chambers, planes

- Bioturbation:
  - Disconnected voids
  - Skeleton grains and fabric lack any orientation.
- Modern roots

Archaeological Evidence:

- Chert flakes and microdebitage

Sampling Location 2

Unit 3a

Sample Block #15, Thin Sections 15.1, 15.2: This fine matrix has a high concentration of calcium carbonates nodules but few inclusions. Carbonates are not stained as much as in sample 13 but that could be because these samples are located a few meters apart. This sample looks very similar to sample 13 but the fabric is not as spongy.

Fine Fraction (Matrix):
- Redoximorphic concentrations:
  - Not Fe stained as much as 13
  - Carbonates are Fe stained
- Carbonates:
  - Lots of carbonates but fewer large clasts

Coarse Fraction (Inclusions):
- Clasts:
  - Limestone and chert clasts

Microstratigraphy:
- Matrix looks similar to 13 but not as spongy

Archaeological Evidence:
- 15.1: finer quartz, does not look like sample 13: finer and more carbonaceous matrix without oriented clay and only one large piece of fat angular chert towards bottom no other MD. One large piece of bone breaking apart.
- 15.2: one piece of thin and sharp chert microdebitage; several pieces of bone; chert flake ca. 1 cm long;

Unit 3a

Sample Block #13, Thin Sections 13.1, 13.2: This spongy_fabric has fine quartz and has dark orange iron staining. Some carbonates are fairly large and are breaking into smaller nodules. There is one chert flake and several modern roots. Clay is oriented along channels as in sample 9, also unit 3a. Fabric is also striated around the pores.

Fine Fraction (Matrix):
- Fine matrix with fine quartz
- Spongy fabric

- <u>Redoximorphic concentrations</u>:
  - Dark orange iron staining

- <u>Carbonates</u>:
  - Several large carbonate nodules fracturing into smaller nodules
  - Gray carbonates that look different than the matrix
  - Compound carbonates
  - Gray carbonates that look different from matrix
  - Carbonate more infused into the matrix

Coarse Fraction (Inclusions):
- One large chert flake
- Modern roots

Microstratigraphy:
- Spongy

- Striated fabric around pores
- Clay coatings along channels

Archaeological Evidence:
- 13.1: several piece of chert microdebitage including one very triangular thin piece of chert, 4-5 pieces of bone
- 13.2: numerous angular piece of chert microdebitage including s thin piece of chert microdebitage, some fragments of bone.

Boundary between Unit 4c and Unit 3b

Sample Block #11, Thin Sections 11.1, 11.2: This unit has a fine matrix with redoximorphic concentrations that are fairly diffuse in the matrix. The microstructure appears spongy and very few large clasts are present.

Fine Fraction (Matrix):
- Fine matrix
- <u>Redoximorphic concentrations</u>:
  - More diffuse iron staining

Coarse Fraction (Inclusions):
- <u>Clasts</u>:
  - Only 1-2 large clasts
  - Quartz silt

Porosity and Microstratigraphy:
- Spongy fabric

Archaeological Evidence:
11.1: 1 possible piece of microdebitage of chalcedonic chert. 1 piece of bone.
11.2: no bone or chert microdebitage

Unit 3b

Sample Block #12, Thin Sections 12.1, 12.2: This sample appears less clayey than samples from unit 3a. The matrix is more uniform and finer than thin section 7f which is coarser and has more clay. One chert flake was found in addition to some fossiliferous limestone and a possible bone or tooth. There are no apparent features of pedogenesis in this sample.

Fine Fraction (Matrix):
- Less clay than Unit 3a (Sample block 9)
- More uniform, finer, better sorted, and more calcite than the bottom of Unit 4b and thin section 7F
- 7F is coarser and has more clay
- 12 is not genetically related to CC or Bk2.
- Mg staining are the black blotchy staining
- Begins to get more coarse towards the top (top of 12.2)

Coarse Fraction (Inclusions):
- fossiliferous limestone
- Poorly crystalline piece of chert

Microstratigraphy:
- It is a sediment for not sure about a soil: lack of pedofeatures
- <u>Bioturbation</u>:
  - Channels and filling

Archaeological Evidence:
- chert flake
- Possible bone/tooth but it is not burnt
- 12.1: one chert flake towards top ca 0.5 cm; no bone or microdebitage
- 12.2: no debitage or bone

Boundary between Unit 4c and Unit 3b

Sample Block #16, Thin Sections 16.1, 16.2: The matrix of this sample is fairly carbonaceous. Some carbonates are stained with iron and others are possible stained by manganese. Carbonates increase in concentration in thin section 16.2 compared to thin section 16.1. A possible piece of charcoal was seen in thin section 16.1.

Fine Fraction (Matrix):
- Fairly carbonaceous matrix
- 16.1 looks more like 12.1 and 12.2 than 7f, is this really unit 3b?
- Redoximorphic concentrations:
  - Carbonates that are stained and some appear to have possible Mg staining?
- Carbonates:
  - 16.2 has a few more carbonate nodules than 16.1 but generally the same fabric
  - 16.1 has fewer carbonates and less coarseness than 7F

Coarse Fraction (Inclusions):
- Possible piece of charcoal at the bottom of 16.1

Archaeological Evidence:
- 16.1: bone fragments, no chert microdebitage
- 16.2 no bone or chert microdebitage

Sampling Location 3

Unit 2

Horizon 4BCkb2 (Thin Section 6497): This sample contains quartz, calcite, chert, limestone, fossils, and shell fragments. Quartz and limestone are rounded and chert is angular. Sorting is moderate to fine. There are angular chert grains that are possibly archaeological (microdebitage). Voids include channels, vesicles, and chambers. Redox concentrations include nodules in the matrix and other concentrations are found in carbonate nodules. Iron staining also appears on the angular chert fragment that appears to be archaeological. Evidence of bioturbation is indicated by disconnected voids and channels. Carbonates are difficult to distinguish from the calcium carbonate throughout the matrix.

Fine Fraction (Matrix):

- Redoximorphic concentrations:
  - Nodules in the matrix
  - Concentrations are found in carbonate nodules.
  - Iron staining also appears on the angular chert fragment
- Carbonates:
  - Difficult to distinguish from the calcium carbonate throughout the matrix

Coarse Fraction (Inclusions):

- Clasts:
  - Quartz, calcite, chert, and limestone
  - Quartz, calcite, and limestone are rounded
  - Chert is angular and possibly archaeological (microdebitage).
  - Fossil and shell fragments

Microstratigraphy:

- Sorting is moderate to fine
- Voids:
  - Channels, vesicles, and chambers

- Bioturbation:
  - Disconnected voids and channels

Unit 2

Horizon 4BCkb (Thin Section 6496): Sample 6496 appears quite different in thin section from the overlying samples. It has a very fine matrix with few mineral grains. The grains that could be found were mostly quartz (rounded) in addition to fossil and shell fragments. The sorting of this sample is moderate to fine and voids include channels, vesicles, and chambers. Redox concentrations are dark orange and only a few are found in the matrix, carbonate nodules, and fossils. Evidence of bioturbation is indicated by disconnected voids and channels.

One-half of this sample was treated with acid (HCl) in order to remove carbonates. In thin section, there is a marked difference in the appearance of the matrix under cross-polarized light and it is nearly all dissolved, signifying a high concentration of calcium carbonate in the matrix.

Fine Fraction (Matrix):
- Appears quite different in thin section from the overlying samples
- It has a very fine matrix with few mineral grains
- Redox concentrations:
    - Dark orange
    - Only a few are found in the matrix, carbonate nodules, and fossils

Coarse Fraction (Inclusions):
- Clasts:
    - Mostly quartz
    - Rounded
    - Fossil and shell fragments

Microstratigraphy:
- Sorting of this sample moderate to fine
- Voids:
    - Channels, vesicles, and chambers.

- Bioturbation:
    - Disconnected voids and channels

Archaeological Evidence:
None.

Unit 1, Horizon 4BCkb (Thin Section 6496- Calcium Carbonate Removed)

- Marked difference in the appearance of the matrix under cross-polarized light
It is nearly all dissolved signifying a high concentration of calcium carbonate in the matrix.

Unit?

Horizon 3Bkb (Thin Section 6495): Sample 6495 contains quartz (rounded), calcite (angular), chalcedony (angular), chert (angular and possible archaeological), limestone (rounded), fossil, and shell fragments. Quartz and limestone are rounded. Calcite, chalcedony, and some chert fragments are angular. It is poorly sorted and the types of voids found are channels, vesicles, vughs, and chambers. The related distribution is porphyric. Redox concentrations are dark orange and found in carbonates and the matrix. Evidence of bioturbation is indicated by disconnected voids and channels. Limestone fragments appear to be burnt and chert and chalcedony grains are iron stained. Carbonates have sharp and diffuse boundaries and are found in the matrix. Neo-calcans are also present.

This sample was also treated with HCl to remove carbonates from a thin section from this horizon. As a result, it was possible to see a significant amount of fine quartz. In addition, it was apparent than much of the matrix dissolved implying that a large amount of the matrix was made up of calcium carbonate. There is a significant amount of fine quartz. Much of the matrix dissolved therefore a large amount of the matrix was made up of carbonate

Fine Fraction (Matrix):

- Redox concentrations:
  - Dark orange
  - Found in carbonates and the matrix
  - Limestone fragments, chert, and chalcedony grains are iron stained
- Carbonates:
  - Sharp and diffuse boundaries
  - Found in the matrix
- Some nodules appear to have septarian cracks.
- Neo-calcans

Coarse Fraction (Inclusions):

- Clasts:
  - Quartz, calcite, chalcedony, chert, and limestone; Quartz and limestone are rounded and calcite, chalcedony, and chert are angular
  - Angular chert is possibly archaeological
  - Fossil and shell fragments

Microstratigraphy:

- Poorly sorted
- Voids:
  - Channels, vesicles, vughs, and chambers
- Porphyric
- Evidence of bioturbation is indicated by disconnected voids and channels

Archaeological Evidence:
Possible chert microdebitage

Unit 4b

Horizon 2Bkb2 (Thin Section 6494): This sample contains quartz, calcite, chalcedony, chert (possible archaeological fragment), and limestone and is poorly sorted. Quartz, chalcedony, chert and limestone are rounded, while some chert is angular. Voids include: channels, vesicles, vughs, and chambers and the related distribution is porphyric. Redox concentrations are dark orange and seem concentrated within pedogenic carbonates and the matrix. Iron staining also appears on limestone and chert fragments. Evidence of bioturbation is indicated by disconnected voids and channels in the matrix. Carbonates are found in the matrix with diffuse boundaries, but many carbonate nodules have holes weathering out from the center. Neo-calcans are also present.

Fine Fraction (Matrix):

- Redoximorphic concentrations:
  - Dark orange
  - Concentrated within pedogenic carbonates and the matrix
  - Iron staining also appears on limestone and chert fragments
- Carbonates:
  - Found in the matrix
  - Diffuse boundaries
  - Many have holes weathering out from the center or infilling of void
  - Neo-calcans are also present

Coarse Fraction (Inclusions):

- Clasts:
  - Quartz, calcite, chalcedony, chert, and limestone
  - Quartz, calcite, chalcedony, chert, and limestone are rounded
  - Some chert is angular and possibly archaeological

Microstratigraphy:
- Poorly sorted.
- Voids:
  - Channels, vesicles, vughs, and chambers
- Porphyric
- Bioturbation:
  - Disconnected voids and channels

Archaeological Evidence:
Possible chert microdebitage

Unit 4c

Horizon 2Bkb1 (Thin Section 6493): Sample 6493 was taken from the second Bk horizon and contains quartz (rounded and angular), calcite (rounded), chert (rounded and angular), chalcedony (rounded), limestone (rounded), and shell fragments. Quartz, calcite, chert, chalcedony, and limestone are rounded. Quartz and chert are also angular. This sample is poorly sorted and there are angular chert grains that are possibly archaeological (microdebitage). Voids include: channels, vesicles, vughs, and chambers and the related distribution is porphyric. Redox concentrations are dark orange and are found in the matrix. Fragments of chalcedony also appear to have iron staining. Evidence of bioturbation is indicated by disconnected voids and channels. Carbonates have sharp and diffuse boundaries and are found in the matrix. Neo-calcans and quasi-calcans can also be found.

Fine Fraction (Matrix):
- Redox concentrations:
  - Dark orange
  - Found in the matrix
- Carbonates:
  - Have sharp and diffuse boundaries
  - Some appear to have septarian cracks
  - They are found in the matrix
  - Neo-calcans and quasi-calcans

Coarse Fraction (Inclusions):
- Clasts:
  - Quartz, calcite, chert, chalcedony, and limestone
  - Quartz, calcite, chert, chalcedony, and limestone are rounded
  - Some quartz and chert clasts are angular
  - Angular chert grains that are possibly archaeological (microdebitage)

- Shell fragments
- Fragments of chalcedony also appear to have iron staining.

Microstratigraphy:
- Poorly sorted
- Voids:
  - Channels, vesicles, vughs, and chambers
- Porphyric
- Bioturbation:
  - Disconnected voids and channels.

Archaeological Evidence:
Possible chert microdebitage

Unit 4c

Horizon 2Akb (Thin Section 6492): This sample contains quartz, calcite, chert, limestone, fossils, and shell fragments. Quartz, calcite, and limestone are rounded. Chert is angular and sorting is poor. There are angular chert grains that are possibly archaeological microdebitage. Voids include channels, vesicles, vughs, and chambers and the related distribution is porphyric. Redox concentrations are dark orange and are found in the matrix and within carbonate nodules. Evidence of bioturbation is indicated by disconnected voids and channels. Fine quartz is distributed throughout the matrix. Carbonates have sharp and diffuse boundaries, are found in the matrix, and most nodules have holes in the center as a result of weathering. Neo-calcans and quasi-calcans are also present.

Fine Fraction (Matrix):
- Redox concentrations:
  - Dark orange
  - Found in the matrix
  - Found within carbonate nodules
- Carbonates:
  - Sharp and diffuse boundaries
  - Found in the matrix
  - Most nodules have holes in the center as a result of weathering or void infilling?
  - Neo-calcans and quasi-calcans

Coarse Fraction (Inclusions):
- Fine quartz is distributed throughout the matrix

- Clasts:
    - Quartz, calcite, chert, limestone
    - Quartz, calcite, and limestone are rounded
    - Chert is angular (possibly archaeological microdebitage)
    - Fossil and shell fragments

Microstratigraphy:
- Sorting is poor
- Voids:
    - Channels, vesicles, vughs, and chambers
- Porphyric
- Bioturbation:
    - Disconnected voids and channels.

Archaeological Evidence:
Possibly archaeological chert microdebitage

Unit 5b

Horizon Bk3 (Thin Section 6491): Sample 6491 was taken from the third Bk horizon and contains quartz, calcite, chert (one angular flake), chalcedony, limestone (appears stained by iron), and shell. Quartz, calcite, and chert are rounded with one angular chert flake. It is poorly sorted. The type of voids include: channels, vesicles, vughs, and chambers. The related distribution is porphyric. Redox concentrations are found in carbonate nodules and in the matrix in a slightly higher concentration than in Sample 6490. Iron staining appears on limestone and chalcedony fragments. Evidence of bioturbation is indicated by disconnected voids and channels. Carbonate nodules have sharp boundaries and are found in the matrix in addition to a few neo-calcans found along macropores.

Another sample taken from this horizon was also thin sectioned and treated with acid (HCl) to remove carbonates. Many of the same characteristics of the untreated sample were seen in this sample except for a large round grain that was made up of many small grains with radial extinction. In addition, redox concentrations remained where carbonate nodules were located. They are also seen on chert fragments. Angular chert fragments are also present and appear to be archaeological. This removal of carbonates confirmed some of the observations made previously on untreated samples.

Fine Fraction (Matrix):

- <u>Redoximorphic concentrations</u>:
  - Found in carbonate nodules
  - Found in the matrix in a slightly higher concentration than in Sample 6490
  - Iron staining appears on limestone and chalcedony fragments.
- <u>Carbonates</u>:
  - Nodules have sharp boundaries
  - Found in the matrix
  - A few neo-calcans are found along macropores

Coarse Fraction (Inclusions):

- <u>Clasts</u>:
  - Quartz, calcite, chert, chalcedony, and limestone.
  - Quartz, calcite, chert, chalcedony, and limestone are rounded
  - One angular chert flake
  - Limestone is stained
  - Shell fragment

Microstratigraphy:

- Poorly sorted
- <u>Voids</u>:
  - Channels, vesicles, vughs, and chambers
- Porphyric
- <u>Bioturbation</u>:
  - Disconnected voids and channels

Archaeological Evidence:
One angular chert flake

Unit 5b, Horizon Bk3 (Thin Section 6491- Calcium Carbonate Removed)

- Many of the same characteristics of the untreated sample were seen in this sample
- One large round grain that was made up of many small grains with radial extinction
- Redox concentrations: remained where carbonate nodules were located
- Iron staining was also seen on chert fragments
- Angular chert fragments are also present and appear to be archaeological

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Unit 5b

Horizon Bk2 (Thin Section 6490): This sample was taken from the second Bk horizon and has a lighter matrix with much more carbonate throughout the matrix than above. It contains quartz, calcite, chert (one angular flake that appears to be archaeological), chalcedony, limestone (appears stained), fossils, and shells. Quartz, chert, chalcedony, and limestone are rounded and calcite and some chert fragments are angular. It is poorly sorted. Voids are made up of channels, vesicles, vughs, and chambers. The related distribution is porphyric. Redox concentrations are medium orange-brown and are found in carbonate nodules and the matrix in a slightly greater concentration than Sample 6489. Evidence of bioturbation is indicated by disconnected voids and channels. Limestone fragments are stained that is possible the result of firing. Carbonates have sharp boundaries that are found in the matrix.

Fine Fraction (Matrix):
- Has a lighter matrix with much more carbonate throughout the matrix than Unit 6b (Thin section 6489)
- Redoximorphic concentrations:
    - Medium orange-brown
    - Found in carbonate nodules
    - Found in the matrix in a slightly greater concentration than Sample 6489
- Carbonates:
    - Possible septarian cracks
    - Sharp boundaries that are found in the matrix.

Coarse Fraction (Inclusions):
- Clasts:
    - Quartz, calcite, chert, chalcedony, limestone
    - Quartz, chert, chalcedony, and limestone are rounded
    - Calcite and some chert fragments are angular
    - Limestone appears stained
    - Fossil and shell fragments

Microstratigraphy:
- Poorly sorted
- Voids:
    - Channels, vesicles, vughs, and chambers
- The related distribution is porphyric

- Bioturbation:
    - Disconnected voids and channels

Archaeological Evidence:
- One angular chert flake appears to be archaeological

Unit 6b

Horizon Bk1 (Thin Section 6489): Sample 6489 was taken from the first Bk horizon of this modern soil. It contains quartz, calcite, chert (some appear archaeological), limestone, and possible fossil fragments, and many intact shells. Quartz, calcite, chert, and limestone are rounded. Some calcite and chert are angular. Sorting is poor. Voids include: channels, vesicles, vughs, and chambers and the related distribution is porphyric. Redox concentrations are orange-brown and mostly found within carbonate nodules, but a small amount are also present in the matrix. Iron staining also appears on chert fragments. Evidence of bioturbation is indicated by disconnected voids and channels. Carbonates have sharp boundaries and are found in the matrix.

Fine Fraction (Matrix):
- Redoximorphic concentrations:
  - Orange-brown
  - Mostly found within carbonate nodules
  - Small amount are also found in the matrix
  - Iron staining also appears on chert fragments
- Carbonates:
  - Nodules with a few septarian cracks
  - Sharp boundaries
  - Found in the matrix

Coarse Fraction (Inclusions):
- Clasts:
  - Quartz, calcite, chert, and limestone
  - Quartz, calcite, chert, and limestone are rounded
  - Calcite and chert are angular
  - Some chert appears archaeological
  - Possible fossils fragments and many intact shells

Microstratigraphy:
- Sorting is poor
- Voids:
  - Channels, vesicles, vughs, and chambers
- Porphyric
- Bioturbation:
  - Disconnected voids and channels

Archaeological Evidence:
Possible chert microdebitage

Unit 6b

Horizon A2 (Thin Section 6488): This sample was taken from the next horizon below and contains quartz, chalcedony, calcite, chert, limestone, and shell fragments. Quartz, chalcedony, calcite, and limestone are rounded and chert is angular. It is poorly sorted and the fabric appears spongy. Voids are made up of channels, vesicles, vughs, and chambers. The related distribution is porphyric. Redox concentrations are dark orange-brown and found predominantly in carbonate nodules, but staining also appears on one piece of chert that appears to be archaeological. Evidence of bioturbation is indicated by disconnected voids and channels. Carbonates with sharp boundaries are found in the matrix.

Fine Fraction (Matrix):
- Fabric appears very "loose"
- Redoximorphic concentrations:
  - Dark orange-brown
  - Found predominantly in carbonate nodules
  - Also staining appears on one piece of chert that appears to be archaeological
- Carbonates:
  - Carbonates are found in the matrix
  - Sharp boundaries

Coarse Fraction (Inclusions):
- Clasts:
  - Quartz, chalcedony, calcite, chert, and limestone
  - Quartz, chalcedony, calcite, and limestone are rounded
  - Chert is angular
  - Shell fragments

Microstratigraphy:
- Poorly sorted
- Voids:
  - Channels, vesicles, vughs, and chambers
- The related distribution is porphyric

Soil Formation Features:
- Bioturbation:
  - Disconnected voids and channels

Archaeological Evidence:
Chert flake?

Unit 7b

Horizon A1 (Thin Section 6487): The first sample was taken from the A horizon of the modern soil that is 10 cm thick. In contrast to the Shell Hash the matrix of this unit is much darker and grainier. The mineral grains include quartz, chalcedony, calcite, chert, limestone, fossils, and shells (in the lower portion of the sample). Quartz, chalcedony, calcite, chert and limestone are rounded. It is poorly sorted and voids include: channels, vesicles, vughs, chambers, and planes. It also appears spongy and the related distribution is porphyric. Redox concentrations are concentrated within pedogenic carbonates and there is no orientation of skeleton grains or fabric. Evidence of bioturbation is indicated by disconnected voids and channels. The calcium carbonate nodules are fine-grained nodules that do not include grains from the matrix. Some chert is stained. Carbonates with sharp boundaries are found in the matrix. Carbonate coats chert fragments that do not appear to be archaeological.

Fine Fraction (Matrix):
- In contrast to underlying Unit 6b, the matrix of this unit is much grainier.
- Redoximorphic concentrations:
  - Concentrated within pedogenic carbonates
  - Some chert is stained
- Carbonates:
  - Nodules are fine and do not include grains from the matrix
  - Sharp boundaries
  - Carbonate coats chert fragments that do not appear to be archaeological

Coarse Fraction (Inclusions):
- Clasts:
  - Quartz, chalcedony, calcite, chert, limestone, fossils, and shells
  - Quartz, chalcedony, calcite, chert, limestone are rounded
  - Fossils and shells are found in the lower portion of the sample

Microstratigraphy:
- Poorly sorted
- Voids: Channels, vesicles, vughs, chambers, and planes
- Fabric is spongy
- Porphyric and no orientation of skeleton grains or fabric
- Bioturbation:
  - Disconnected voids and channels

VITA

Heidi Marie Luchsinger
Department of Anthropology
MS-4352
Texas A&M University
College Station, Texas, 77843
Luchsinger@tamu.edu

Education:

Barnard College, New York, New York: B.A., Ancient Greek and Latin, 1996.

Texas A&M University, College Station, Texas: M.A., Anthropology, 2002.

Fieldwork Experience:

Survey, excavation, and geoarchaeological fieldwork in Greece, Turkey, England, and Texas.

Relevant Coursework:

Geoarchaeology, Ceramic Petrography, Soil Morphology, Soil Microfabric Analysis, Pedology, Geomorphology, Texas Prehistory, Lithic Technology, First American Studies.

Publications:

Luchsinger, Heidi and Paul Goldberg (submitted)
Micromorphological Analysis of Sediments at the Pavo Real Site (41BX52), in *Excavations of the Pavo Real Site (41BX52)*. Texas Archaeological Research Laboratory, Austin, Texas.

Research Interests:

Geoarchaeology, Micromorphology, and Paleoindian Archaeology.